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Metal Progress

Ernest E. Thum, Editor

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AMERICAN SOCIETY for METALS

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Effect of Water Vapor on Magnesium Alloys During Heat Treatment

IN THE SOLUTION treatment at 720 to 730° F. of magnesium alloys containing 6% aluminum and 3% zinc, an apparently anomalous behavior is occasionally encountered in the susceptibility of this alloy to "heat treat burning". The condition will occur occasionally without appearing on either previous or subsequent batches reaching the heat treating department. "Heat treat burning" has been ascribed to water vapor in the furnace atmosphere, and this paper presents some observations on the effect.

Heat treat burning manifests itself in three ways: *(a)* exudation on the surface of the casting; *(b)* formation of a gray-black powder on the surface of the casting; *(c)* voids on the surface and interior of the section being heat treated. The intensity of "burning" varies from none to the point where actual combustion occurs.

The nominal composition of the alloy used in this investigation was aluminum, 6.0%; zinc, 3.0%; manganese, 0.15% min.; silicon, 0.30% max.; copper, 0.05% max.; nickel, 0.01% max.; other impurities, 0.30% max.; magnesium, remainder. A solution temperature range commonly used for this alloy is 720 to 730° F.

Heat treat burning can be caused by solution temperatures above 730° F., or by failure to preheat as-cast material slowly in the range from 650 to 725° F. It has been observed, however, that burning can occur when neither of these conditions is violated. During an entire 2½-year period, this "burned" condition appeared on one laboratory furnace charge and on four production furnace loads; no other batch was visibly affected. In the laboratory, SO_2 was not regularly introduced into the furnace atmosphere, while all production batches were heated in an atmosphere containing 0.5% SO_2. On the last production load showing this condition there was reason to believe that the SO_2 flow had been interrupted and that there was an appreciable amount of water vapor in the furnace atmosphere. (It is interesting to note that no instance of burning was observed during the winter months.) An investigation was therefore carried out at Dodge-Chicago plant to determine the effect of water vapor in the presence and absence of SO_2 in the furnace atmosphere.

Procedure

The atmosphere being investigated was bubbled at the rate of 180 cc. per min. through an Erlenmeyer flask containing water at 175° F. This rate introduced 4 g. of water per hr. when air was used as the medium. The discharge end of the flask was connected to an iron pipe which extended through the cover of the furnace and discharged the humidified gas into another flask, inside the furnace, containing the samples. The discharge end of the iron tube was within 2 in. of the samples. The gas escaped from the furnace flask between the iron pipe and the neck of the Erlenmeyer.

For control purposes, several samples of each type were placed in a weighing bottle covered with a ground glass and the bottle placed in the furnace beside the Erlenmeyer flask. While the seal was not perfect, the rate of flow of the atmosphere over these control samples was little or nothing.

Three types of samples were selected from sand castings, as follows:

Fig. 1 — Cubes, Walls and Bars (at Top, Middle and Bottom), Heated in Humid Atmosphere (Left) and in Comparatively Dry (Right), Both Free of SO_2, 12.5 Hr. at 730° F.

$\frac{3}{8}$-in. cubes cut from the $1\frac{3}{4}$-in. wall of a production casting. These will be referred to in what follows as "cubes".

A portion of a $\frac{3}{16}$-in. wall cut from a production casting, hereinafter called "wall".

A $\frac{3}{4}$-in. shoulder from a test bar, called "bar" from time to time in the text.

After sawing, the samples were polished through No. 0 abrasive paper on one face.

Several samples of each type — cube, wall and bar — were put in the Erlenmeyer flask inside the heat treating furnace. Corresponding samples were placed in the covered weighing bottle. The gas flow was started at the beginning of the following solution treatment cycle:

1. Start furnace below 500° F.
2. Heat to 650° F. and hold 15 min.
3. Heat from 650° F. to solution temperature indicated in 2 hr.
4. Hold at temperature for times indicated.
5. Remove from furnace and air cool.

Samples were tested under four conditions, namely: humidified air, humidified SO_2, and humidified air carrying 0.6% SO_2, all at 730° F.; and humidified air at 715° F.

Results

Humidified Air at 730° F. — In the first test, compressed air was humidified and flushed over

Fig. 2 and 3 — Microstructure at 40× of Cubes Shown at Top Left and Right of Fig. 1, Respectively

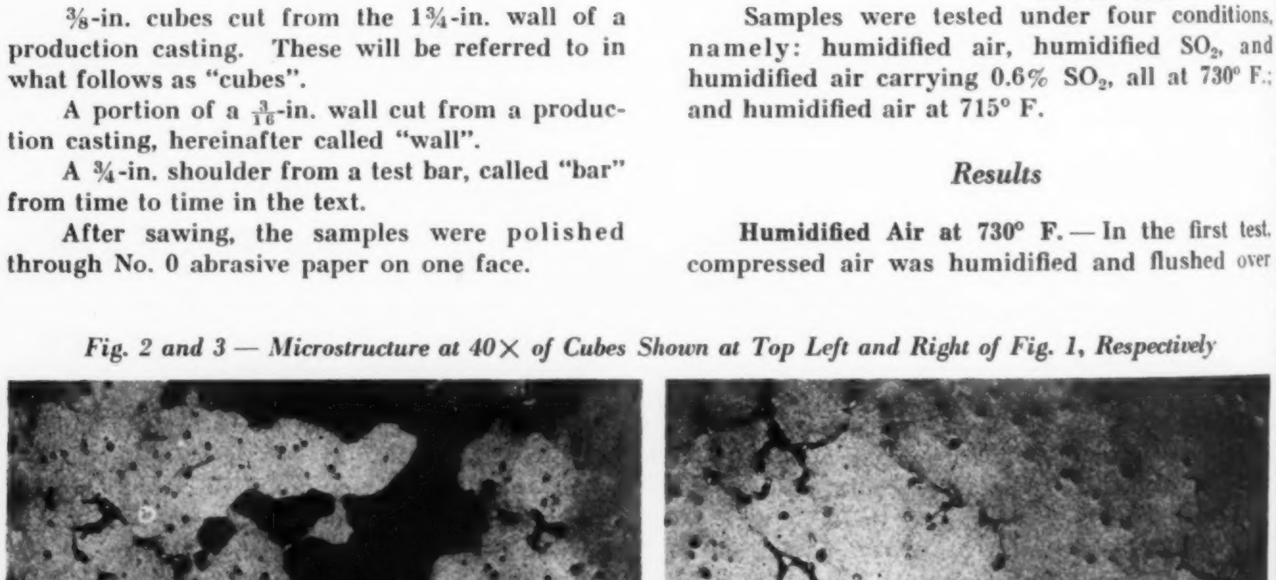
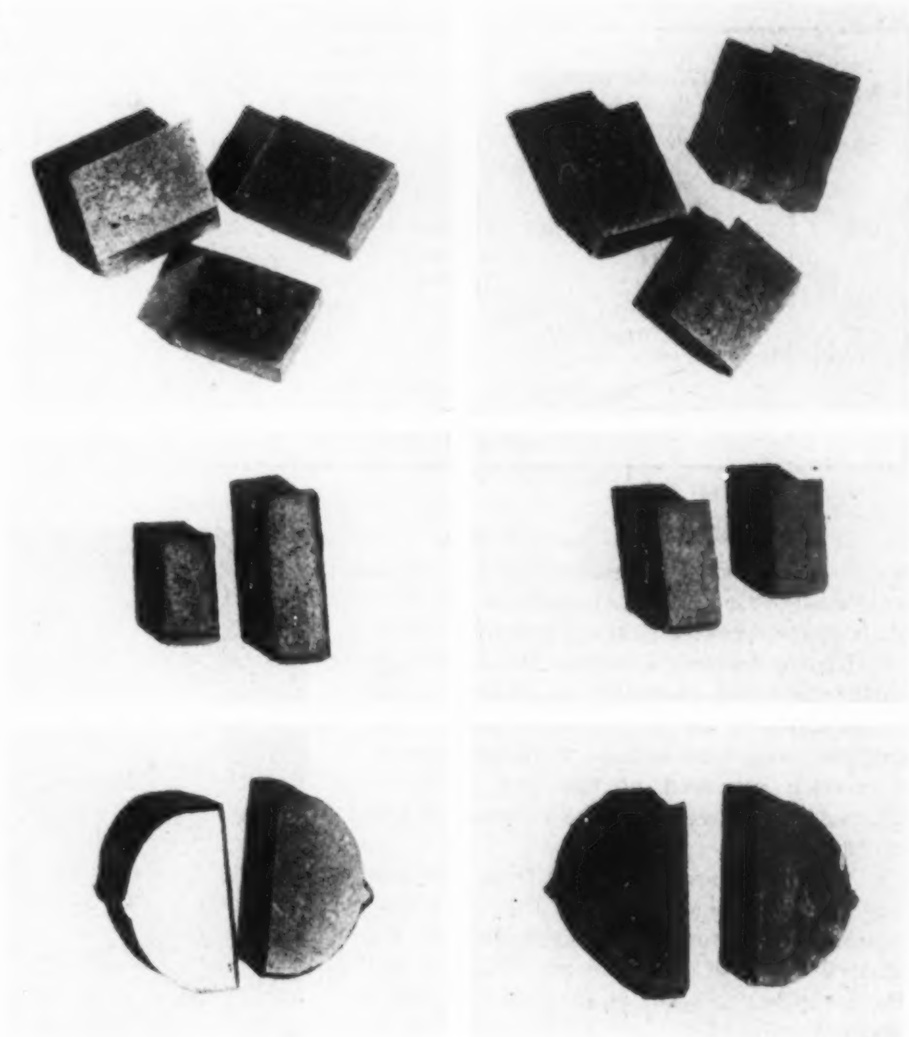


Fig. 4 — Cubes, Walls and Bars (Top, Middle and Bottom Respectively), Heated in Humid Atmosphere of Commercial SO_2 and in Dry, SO_2-Free Air (Right), 14.5 Hr. at 730° F.



the samples for 12½ hr., maintaining a solution temperature of 730° F. The results obtained are shown in Fig. 1, in which the samples subjected to the humidified air are on the left and the control samples on the right. Samples at the top are cubes from the 1¾-in. section, those in the center are walls from the $\frac{3}{16}$-in. section and the bottom pieces are bars from the ¾-in. diameter shoulder of the test bar.

It will be observed that heat treat burning is exceptionally severe in the cubes when subjected to the humid air. The thinner walls do not appear appreciably affected. There is some burning in the heavy sections of the control cubes (upper right of Fig. 1); this may be due to some

Fig. 5, 6, and 7 — Structure of Cubes Heated as Follows: 14.5 Hr. at 730° F. in Humid Atmosphere of Commercial SO_2; 12 Hr. at 730° F. in Humid Atmosphere With 0.6% SO_2; 12 Hr. at 715° F. in Humid Atmosphere (40×)

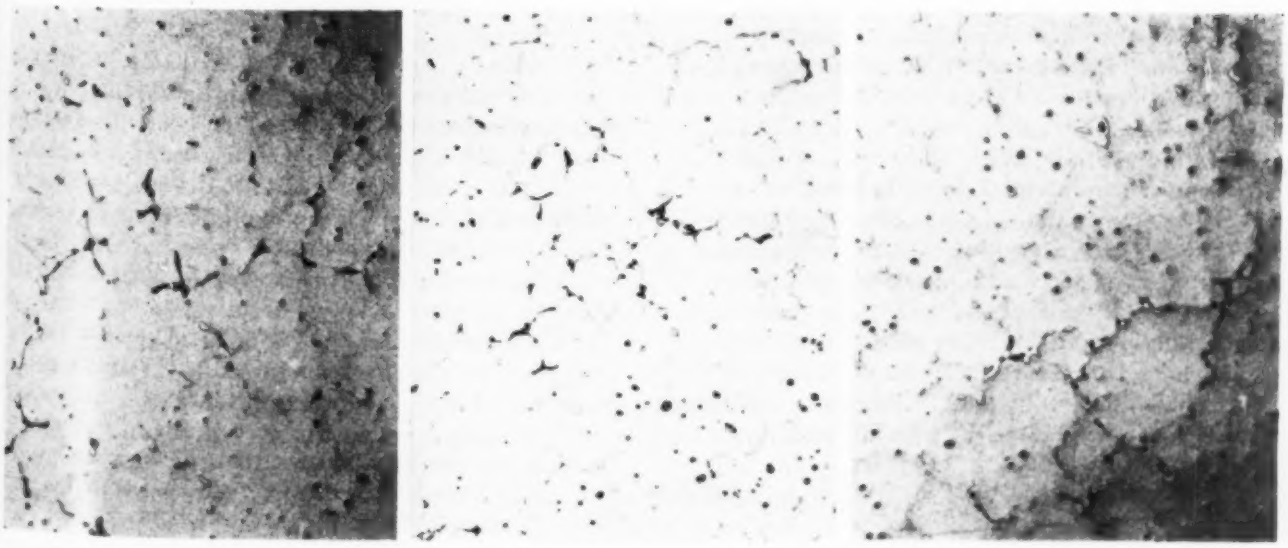


Table I — Effect of Atmosphere on Heat Treat Burning

Temperature	Time	Conditions	Sample	Original Section Size	Porosity Rating	Beta Compound Rating
730° F.	12½ hr.	humid air	Cube	1¾ in.	10	4
			Bar	¾ *	2	1 to 3
			Wall	3/16	2	0
730	14½	humid SO_2	Cube	1¾	5	4 to 5
			Bar	¾ *	1	1 to 2
			Wall	3/16	1	0 to 1
730	12	humid air with 0.6% SO_2	Cube	1¾	6	5
			Bar	¾ *	0	3 to 4
			Wall	3/16	0	1
715	12	humid air	Cube	1¾	1	6
			Bar	¾ *	0	3 to 4
			Wall	3/16	0	3

*Shoulder of test bar.

water vapor leaking into the control sample weighing bottle. It is obvious, however, that burning decreases with the atmospheric flow.

Figure 2 shows a section taken through one of the cubes shown at upper left of Fig. 1. Practically no beta compound remains and the voids tend to have rounded corners. A sample removed at the end of 4 hr. showed about one-third the damage shown in Fig. 2.

Figure 3 shows a section from the control sample, upper right in Fig. 1. Here, again, the burning is less severe than in the sample exposed to humid air (Fig. 2), but the inception of voids at the beta compound areas is evident.

Humidified SO_2 at 730° F. — When compressed air was replaced by a flow of humidified commercial SO_2 the burning was eliminated (Fig. 4), thus indicating the beneficial inhibiting action of the SO_2. Figure 5 was taken from a sample in the upper left of Fig. 4 and shows the resulting microstructure. Some of these voids may be microshrinkage, since the cubes from 1¾-in. sections were not completely sound.

Humidified Air With 0.6% SO_2 at 730° F. — Since most commercial heat treating is carried out using approximately 0.5% SO_2, the experiment at 730° F. just described was repeated using a combination of SO_2 and humidified compressed air which showed on analysis 0.6% SO_2. The results were indistinguishable from those shown in Fig. 4 and it may be observed that this quantity of SO_2 is as efficient as 100% SO_2. Figure 6 was taken from a sample subjected to humidified air containing 0.6% SO_2.

Humidified Air at 715° F. — We then tried the effect of reducing the solution temperature to 715° F. with humidified air as an atmosphere. Visual comparison of the samples with those of Fig. 1 and 4 showed them to be practically as good as Fig. 4, thus proving the pronounced beneficial effect of the lower temperature on suppressing the tendency for heat treat burning in the presence of water vapor. Figure 7, a photomicrograph of one of the cubes so treated, shows no appreciable heat treat burning.

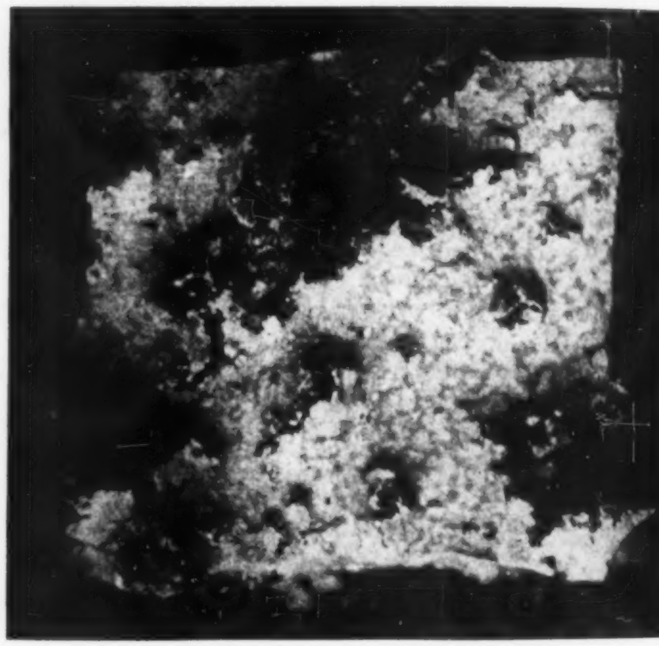


Fig. 8 — Cube From Upper Left of Fig. 1 at 6×

Results are summarized in Table I. It may be observed that under all conditions, the porosity and beta compound ratings decrease with decreasing section size. The porosity rating decreases with SO_2 in the atmosphere and with lower solution temperature. The compound rating is slightly greater at 715 than at 730° F.

Results of this investigation would indicate that at a solution heat treating temperature of 730° F. burning may occur in a magnesium alloy containing 6% aluminum and 3% zinc in the absence of SO_2 and in the presence of water vapor.

Possible sources of water vapor in the atmosphere in a production heat treating furnace are:

1. Normal amount of water vapor in the air.
2. Possible water vapor in the SO_2.

3. Formation of hygroscopic water in iron sulphate which forms inside heat treating furnaces lined with sheet steel and using SO_2. This amount of water may be appreciable, particularly if the furnace has been allowed to cool to 70° F.

4. Occasional water in the pits beside the heat treating furnaces.

Although this work was not comprehensive enough to permit a determination of the mechanism of heat treat burning, speculation on this point is worth while.

Figure 8 shows a cube cut from the 1¾-in. sample — one of those shown in upper left of Fig. 1 — at somewhat greater magnification. The areas of burning are eruptions from the surface and appear like small volcanoes, indicating pressure from within. It seems, therefore, that burning might occur in the following manner:

At about 730° F. the beta compound undergoes expansion — possibly a solid-to-liquid phase change — which results in the formation of "beads" on the surface of the castings. In the presence of water vapor this material undergoes oxidation with a further increase in volume, forming the craters seen in Fig. 8. In the interior of the section, when the casting cools, there is contraction of the beta material and, because of high frictional losses and low head pressure, the previously sound areas now have a deficiency of beta with consequent formation of voids.

Conclusions

The following conclusions may be drawn from this investigation:

1. Water vapor at 730° F. is detrimental to this alloy.

2. SO_2 has a definite inhibiting effect on burning in amounts as small as 0.6%.

3. Heat treating at 715° F. appears to prevent burning even in the presence of appreciable quantities of water vapor. The solution of beta compound is not as complete, however, as after heating at 730° F.

4. The tendency for burning increases with increase of section size in the range studied.

5. The burning begins in the areas of beta Al-Mg-Zn compound.

Precise Measurements and Inspection by Stereoscopic Radiography

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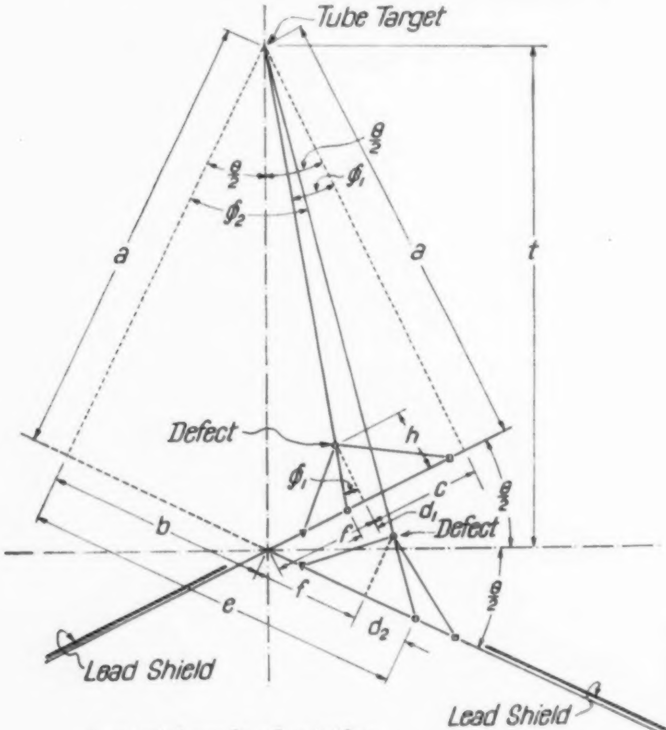
RADIOGRAPHIC examination and inspection began to appear among the usual requirements of high-grade specifications for both metallic and nonmetallic materials during the years immediately preceding World War II. The introduction of this searching as well as nondestructive method of testing has greatly improved the reliability of inspection for hidden internal defects and has realized formerly unattainable standards of quality. Furthermore, these improvements have been supplemented by economic gains, because radiographic inspection has provided efficient means of studying the location, distribution, and size of internal defects and, hence, of recognizing and eliminating their cause, thus simultaneously reducing scrap losses and manufacturing costs.

The extent to which radiographic inspection is employed in hollow steel blade manufacture by the Propeller Division of Curtiss-Wright Corp. may serve to illustrate its industrial importance. During peak operation, this company operated a total of nine X-ray units in its two steel blade

Fig. 1 — Scheme for Double Exposure on Rotated Object, Together With Geometric Derivation of Formulas to Calculate the Position of a Defect From Known Angle of Rotation and Measured Relative Displacement of Images



θ = total angle of rotation

t = distance from target to axis of rotation

h = defect-film distance (normal)

d_1 and d_2 = displacements from normal projection $= h \tan \phi_1$ and $h \tan \phi_2$

$$D = d_1 + d_2 = h\,(\tan \phi_1 + \tan \phi_2) \qquad (1)$$

$$a = t \cos \frac{\theta}{2} \qquad (2)$$

From geometry of figure

$$b = a \tan \frac{\theta}{2}$$

$$c = (a - h) \tan \phi_1$$

$$e = a \tan \phi_2$$

$$f = b - c$$

$$d_2 = e - b - f = e - 2b + c$$

$$= a \tan \phi_2 - 2\,a \tan \frac{\theta}{2} + (a - h) \tan \phi_1 = h \tan \phi_2$$

$$\text{whence } \tan \phi_2 = \frac{2\,a \tan \frac{\theta}{2}}{a - h} - \tan \phi_1$$

Substituting in (1)

$$D = h \tan \phi_1 + h \left(\frac{2\,a \tan \frac{\theta}{2}}{a - h} - \tan \phi_1 \right) = \frac{h \cdot 2\,a \tan \frac{\theta}{2}}{a - h}$$

$$\text{or } h = \frac{Da}{2\,a \tan \frac{\theta}{2} + D}$$

$$\text{Substituting (2)} \qquad h = \frac{Dt \cos \frac{\theta}{2}}{2\,t \sin \frac{\theta}{2} + D} \qquad (3)$$

plants, and these units consumed 274,000 sq.ft. of film per month. Each propeller blade is radiographed four times at various stages of manufacture in order to weed out defective blades at the earliest possible operation, and insure that all blades accepted for shipment be of reliable quality.

The versatility and usefulness of radiographic inspection has been extended through the comparatively recent introduction of densitometric thickness measurements and the development of micro and stereographic radiography. The densitometric method was described in an article by H. P. Moyer entitled "X-Rays Now Gage Propeller Blade Thickness", published in *Aviation*, V. 43, No. 3, March 1944. The present article is concerned with the stereographic method, which has been experimentally adapted to the measurement of wall thickness of hollow steel propeller blades and the determination of the exact location of minor defects in the materials of construction which might or might not be deleterious to the performance of a propeller blade, depending upon whether they are located in areas characterized by a high stress level.

Stereographic radiography has been practiced for several years but the methods usually employed were somewhat cumbersome, depending either upon calculations from two exposures or upon stereoscopic measurements with improvised equipment of low accuracy.

All such methods, new or old, require two exposures of the area with the radiation at different angles. As a rule this effect is obtained by the rotation of the object while the X-ray tube remains stationary. When the geometry of the setup is known, the location of a defect can be determined from stereoscopic observation and measurements, or it can be calculated from the displacement of corresponding points on the two images of the defect with relation to each other, as explained in a somewhat simplified manner in Fig. 1. To obtain precise measurements of the location of a defect, it is necessary to control the rotation used between exposures; for the final determinations, it is obviously desirable to have an instrument equipped with means for accurate and direct depth readings. So far as known to the author, the only instrument that permits such accurate and direct readings from two simple exposures is the so-called Orthoscope, marketed by Gutterson and Co., Inc., 420 Lexington Ave., New York. This instrument was adapted specifically to hollow blade inspection during the final stages of its development.

Figure 1 illustrates the method of exposure of stereographic radiographs employed in experimental work at the Propeller Division of Curtiss-Wright Corp. The external blade surface is

provided with "landmarks" in the form of tungsten carbide pellets whose X-ray images allow the blade surface to be "seen" in the Orthoscope. The blade is rotated about its longitudinal axes so that its positions during the two exposures are symmetrical about a plane perpendicular to the axis of the X-ray beam. One half of the film is shielded during the first exposure and the other half during the second exposure. An automatic device controls both the blade rotation and the shifting of the shield and film. Equation (3) shows how the "depth" of the defect can be computed from the distance of the X-ray target from the center of rotation, the half-angle of rotation and the measured displacement of the image on the film.

Figure 2 shows the working principles of the Orthoscope for viewing a film exposed as indicated in Fig. 1. It has two pairs of parallel iridium-plated mirrors, each pair of which is set at a 45° angle with the plane of the film under observation. Each eye sees only the image transmitted by one of the pairs of matched mirrors, and the two images appear as slightly different views of a single object — which in reality is a virtual image created by the two X-ray negatives. Figure 3 is a photograph of the actual instrument; the mirrors are in the upper component which resembles a desk lamp.

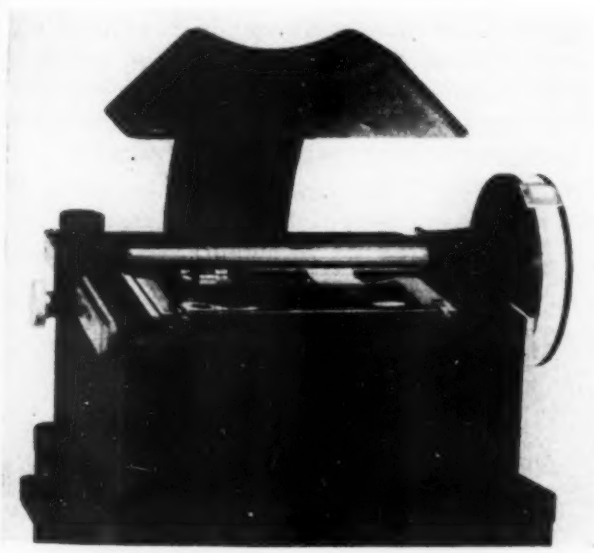


Fig. 3 — Photograph of Complete Instrument

Since the Orthoscope has no other optical components than plane mirrors, it requires no focusing. It determines the vertical position of a landmark or a defect by means of two identical hair crosses located in the plane of the film (see Fig. [illegible]). The horizontal distance between the crosses is measured by a micrometer arrangement and any variation in this distance is, of course, interpreted by the eyes as vertical motion. The crosses also can be moved over the films without changing the horizontal distance between them and they then appear to move in a horizontal plane. Variations in the distance between the crosses can be calibrated against depth either by calculation or empirically. On the Orthoscope, the "depth" dial is calibrated directly in mils. The illusion of depth, of course, can be increased by increasing the angle of rotation of the films between exposures, but rotations other than the standard would require a recalibration of the dial.

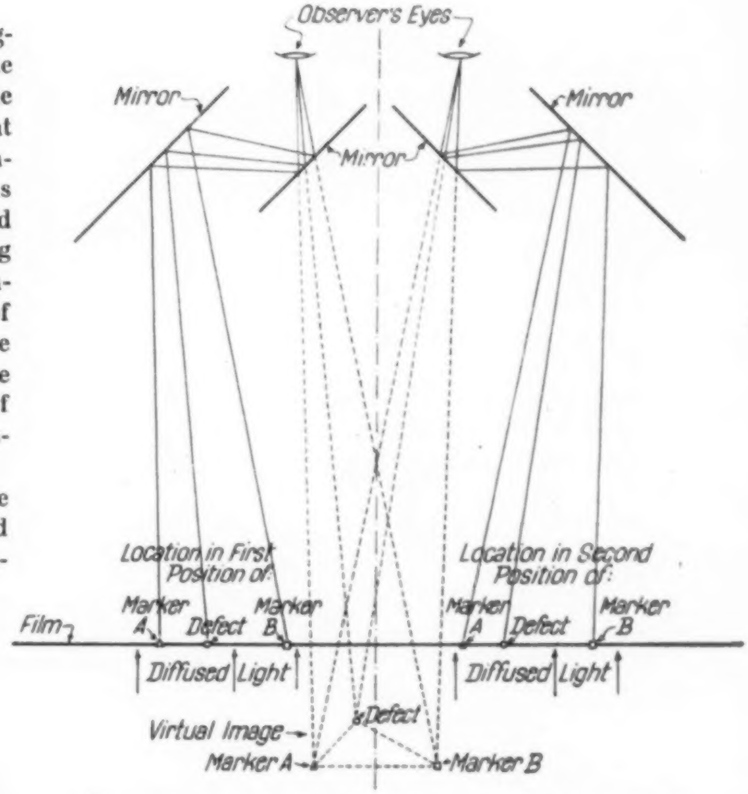


Fig. 2 — Method Whereby Orthoscope Produces Virtual Image by Single View of Double-Exposed Film

This method of stereoscopic inspection is also applicable to plate thickness measurements, sometimes required to supplement magnaflux or ordinary X-ray inspection. Such determinations are illustrated by Fig. 4, showing a transverse section through the edge of a Curtiss hollow steel propeller blade with internal brazed copper fillets (serving to relieve stress concentrations caused by weld imperfections). The important dimensions that occasionally require checking by stereo-radiographs, are X, X' and X''.

With the aid of tungsten carbide landmarks, the X dimension could be measured to within ±0.005 in. and X'' to within ±0.006 in. X' could

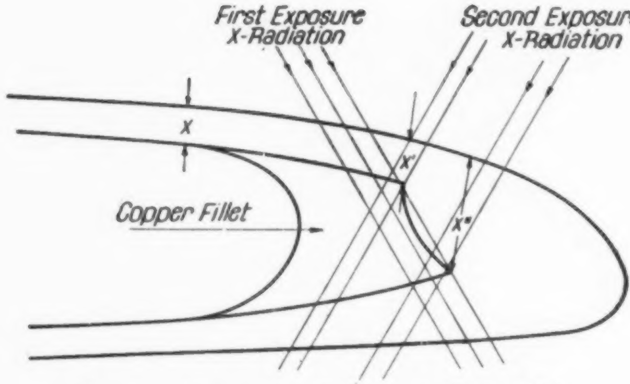


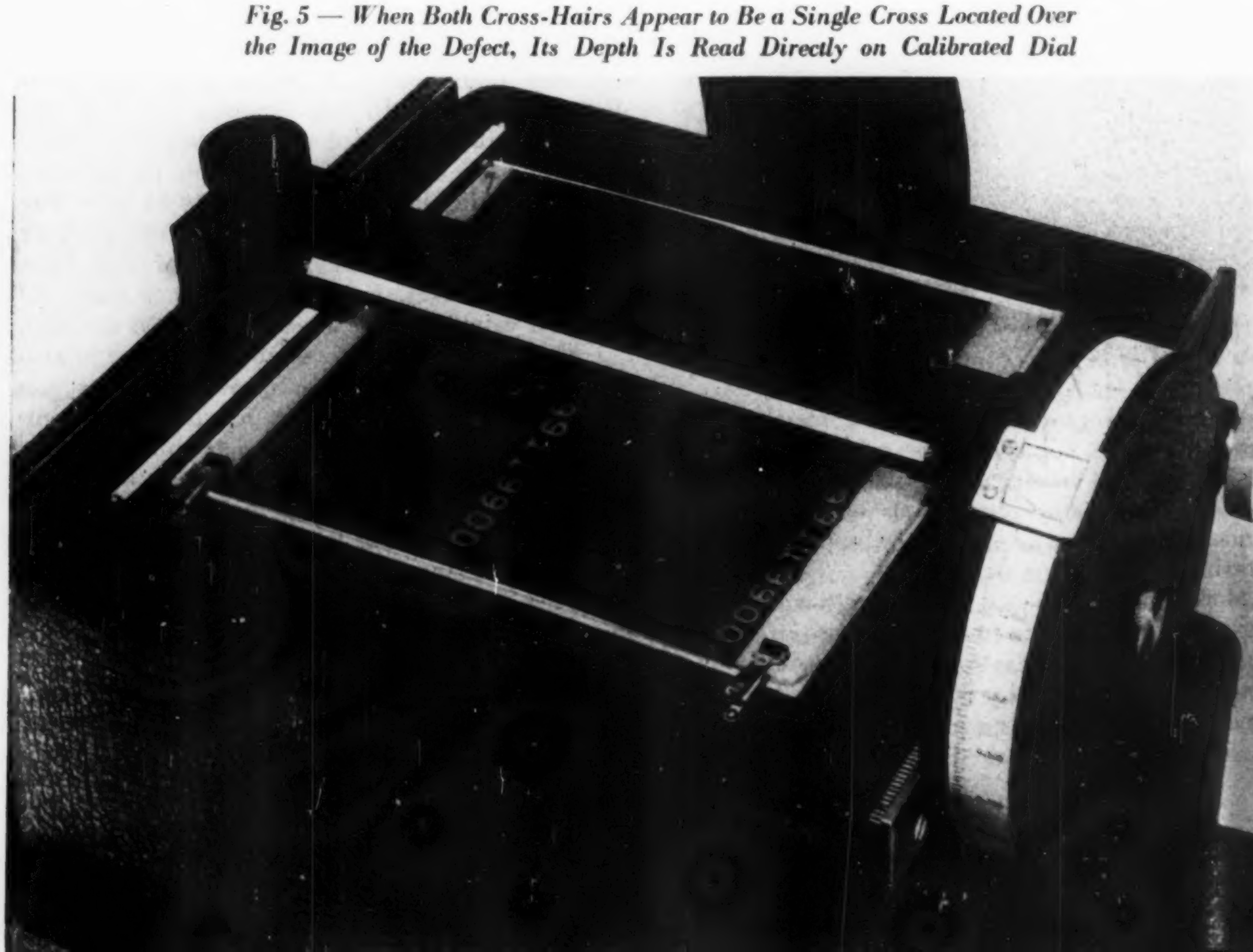
Fig. 4 — Transverse Section of Blade With Angle of Radiation in the Two Exposures

not be determined with satisfactory precision because of the peculiar copper and steel combination in the path of the X-ray. Radiographically, copper is somewhat denser than steel, and at X'', the differences in absorption affecting rays to the left and right of the internal edge in the two exposures are sufficient to locate the edge. However, with the rays penetrating in toward the left, the absorption of the composite at X' does not change abruptly enough to permit the desired measurements.

To measure plate thickness it is generally possible to introduce tungsten carbide pellets on the inside of a blade — as on the surface of an inflated rubber bag. Experience has shown that different observers are able to check readings of the vertical positions of the pellets within a range of 0.0025 in., and such methods should therefore allow measurements of plate thickness with an accuracy of ±0.003 in. In Fig. 4, X and X'' could have been measured with the same high precision except for the gradual change in the thickness of the copper fillet at X in the path of the X-ray, which accounts for the lower accuracy of ±0.005 to ±0.006 in.

The stereometric method described above possesses certain advantages over the densitometric method that has been used by Curtiss Propeller Division since 1941 and was developed independently of the work conducted by H. P. Moyer of the American Propeller Co. (described in *Aviation* for March 1944). These stereographic measurements can be used to locate defects at any depth in a section, whereas the densitometric method is able to determine only the total material thickness. With the aid of the Orthoscope, the stereographic measurements can be obtained directly from a few readings, whereas densitometric determinations require comparatively numerous readings, and each thickness determination must be calculated on the basis of the individual calibration of each X-ray exposure. These advantages of stereographic exposure more than outweigh its somewhat more elaborate procedure.

Fig. 5 — When Both Cross-Hairs Appear to Be a Single Cross Located Over the Image of the Defect, Its Depth Is Read Directly on Calibrated Dial



Wartime Developments in Steel Castings*

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ALTHOUGH wartime developments in the gray iron and malleable iron industries noted in the article in last month's *Metal Progress* have been far reaching and significant, the applications for the products have been somewhat limited by the nature of the materials used. No such limitation has hampered the steel foundries, since their material is the same as is used in other methods of manufacturing steel and the difference is only in the method of processing. This is best evidenced by the steel foundry output, which has increased by over 300% since 1939 to 2,743,000 tons for 1943.

Melting—The equipment used by the foundries for melting the steel has not altered to any considerable extent, with one exception, namely, the application of bessemer converters. A number of steel foundries, in particular those manufacturing large quantities of smaller castings, are now using what has been termed the triplex method, where the raw materials are melted in the cupola, the iron blown in the converter and then transferred to electric furnaces for further refining and alloying additions.

There has been much argument as to the advantages and disadvantages of these new methods, but the writer can truly state, from his own experience, that for mass production, the triplex method has been a happy solution when a continuous flow of metal is required.

Molding — The advances made in new mold materials referred to in the article on gray iron in last month's *Metal Progress* apply equally to the steel foundry. The molding technique has also been greatly improved as a result of extensive studies of internal stresses, mass effect, directional solidification, and the introduction of the so-called atmospheric pressure method of risering. Considerable use of ceramic glazes for mold washes provides a new method of approach to the problems of "metal penetration" and the deleterious effect of mold gases.

*This is the second portion of a paper presented before the Hartford Chapter ⊖ last winter. The first portion "Developments in Gray Iron and Malleable" was printed in the June issue of *Metal Progress*. The author wishes to express his appreciation to the Ford Motor Co. for permission to use equipment, facilities and records in the preparation of his address.

Fig. 1 — Two 155-Mm. Cast Steel Armor-Piercing Shells After Penetrating 3-In. Plate Set at 35° Angle

The general trend in core making is toward the increased use of synthetic binders. Work on various refractory materials for cores, such as glass and others, shows considerable promise for special applications.

Alloys and Heat Treatment — By far the greatest advance in the steel foundry has been accomplished through the increased utilization of alloys and the extensive application of liquid quenching in the heat treatment of castings.

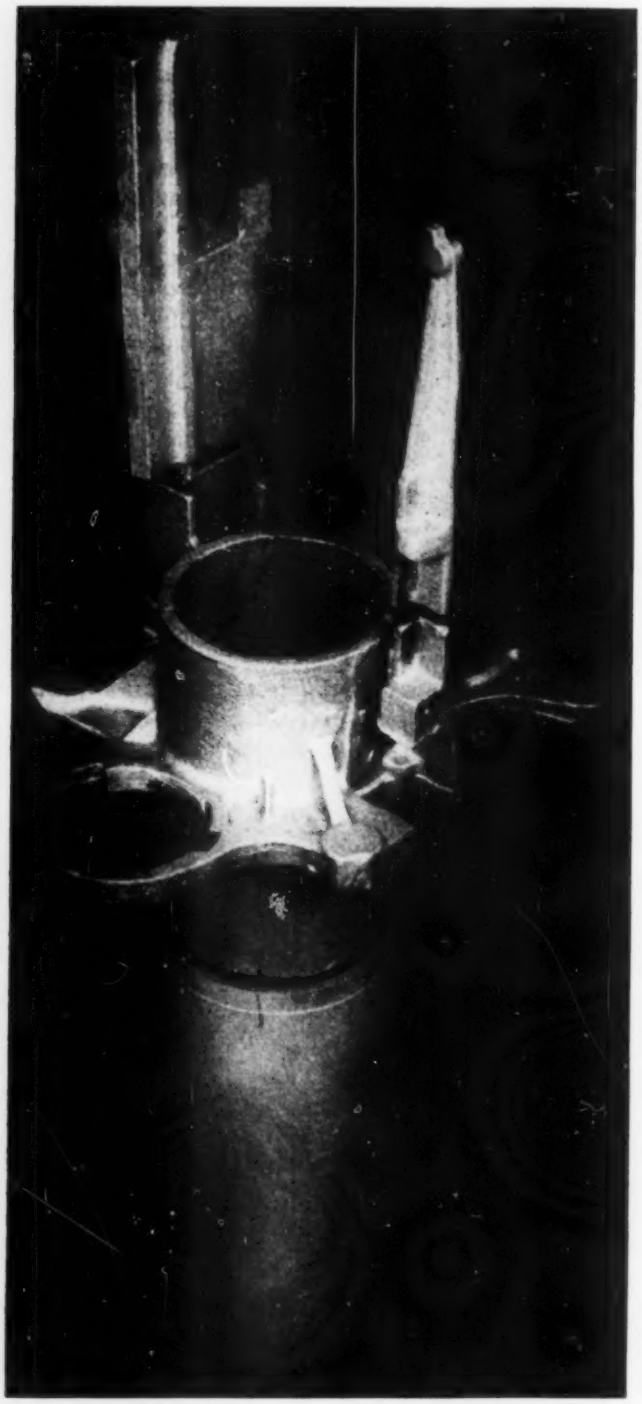

Fig. 2 — Recoil Cylinders for 75-Mm. Gun — an Example of a Welded Assembly of Steel Castings That Requires Highest Quality and Shock Resistance

Whereas the steel foundries prior to the war were not important users of alloys (with the exception of manganese, and small amounts of molybdenum, copper and nickel), the vastly increased requirements of physical and other properties have resulted in the adoption of steels whose composition is similar to those used in the wrought steel industry. Modifications of types such as the S.A.E. 4100, 5100, 8400, and 8600 series are today accepted analyses of cast steels.

Extensive studies of hardenability have resulted in much better understanding of this all-important factor in obtaining maximum physical properties. Such information underlies the advance in heat treat technique. It is indeed encouraging to note that many steel foundries today are using Jominy hardenability tests as a routine method in manufacturing control.

Considerable attention is being focused on new steel specifications. It is to be hoped that before long detailed chemistry will be eliminated from the specification except for carburizing and weldable grades. Specifications should instead be based on physical properties obtained through a test coupon made in a standardized way, to indicate the response of the material to a predetermined heat treatment, coupled with hardenability factors indicating the minimum and sometimes the maximum hardness and distance on the Jominy bar for any particular carbon range and critical thickness.

Isothermal annealing, austempering and martempering treatments are rapidly finding increased applications in the heat treatment of certain types of steel castings.

Inspection and Control — Largely through the efforts of the Army and Navy Ordnance Departments, much attention is now being paid to the soundness of castings. This has resulted in the adaptation of radiography as a standard means for inspection in steel foundries. Several X-ray units of million-volt capacity are in operation and several two-million-volt units are under construction.

Supplementing the X-ray, magnetic particle inspection and similar methods have also been utilized.

Much attention is also directed toward improved methods of process control and, through the effort of the Society of Automotive Engineer's War Engineering Board, recommended methods have now been worked out and published.

Of importance also are the recommended

Fig. 3 — Welded Construction of Diaphragm for Aircraft Engine Supercharger. The supercharger is a turbocompressor, driven by hot exhaust gas, and the "diaphragm" is a series of fixed vanes that direct the hot gas against the turbine buckets at the correct angle. In the construction shown the individual vanes are welded into slots in an inner and outer cast ring. All this is replaced now by a single casting, and the vanes themselves have airfoil cross sections

methods for repairing defective gray iron, malleable and steel castings which the Iron and Steel Committee of the S.A.E. has worked out at the request of the Ordnance Department and which have brought this whole subject out in the open.

Typical Applications—In order to demonstrate the variety of uses to which steel castings have been put during the war and their importance in replacing fabricated assemblies and forgings, as well as their usefulness as component members in welded assemblies and for high-temperature work, a selection of typical parts will be briefly described and some of them illustrated.

Of all the assignments given the steel foundry industry during the war, none produced greater trouble than the casting of armor. No standards were available covering chemical composition, and the conventional methods of testing used in the past did not prove satisfactory to judge the behavior and qualities of this type of material, whose acceptance is based on ballistic performance only — that is, the penetration of a projectile.

The compositions first cast followed the trend of World War I, when high-alloy rolled armor steels were used. The serious shortage of alloys, however, resulted in extensive research which ultimately produced satisfactory low-alloy cast armor compositions which not only saved large tonnages of critical alloys, but — what is more important — have produced large and complicated castings which replaced many large fabricated assemblies for hulls, turrets, and transmission cases for tanks and armored cars. Numerous other smaller items were made of new alloys, thereby greatly simplifying the manufacturing processes with resultant saving in time and labor.

Many pictures were published during the war of American tanks, and readers will recall the transition in shape and silhouette from a structure composed of flat and bent plates with many square corners, to a functional body, smooth and rounded and offering the minimum frontal area for direct enemy attack. This important change in shape, with an equally important increase in durability, was possible only by the perfection of cast steel armor.

Other important steel castings were used in armored equipment, of course, ranging from fan shrouds for the engine to axle housings, but these are items which have their peacetime counterparts — although of less rugged construction.

Extensive research which has been conducted in the development of better welding techniques and improved welding rods has increased the use of castings as component members in welded

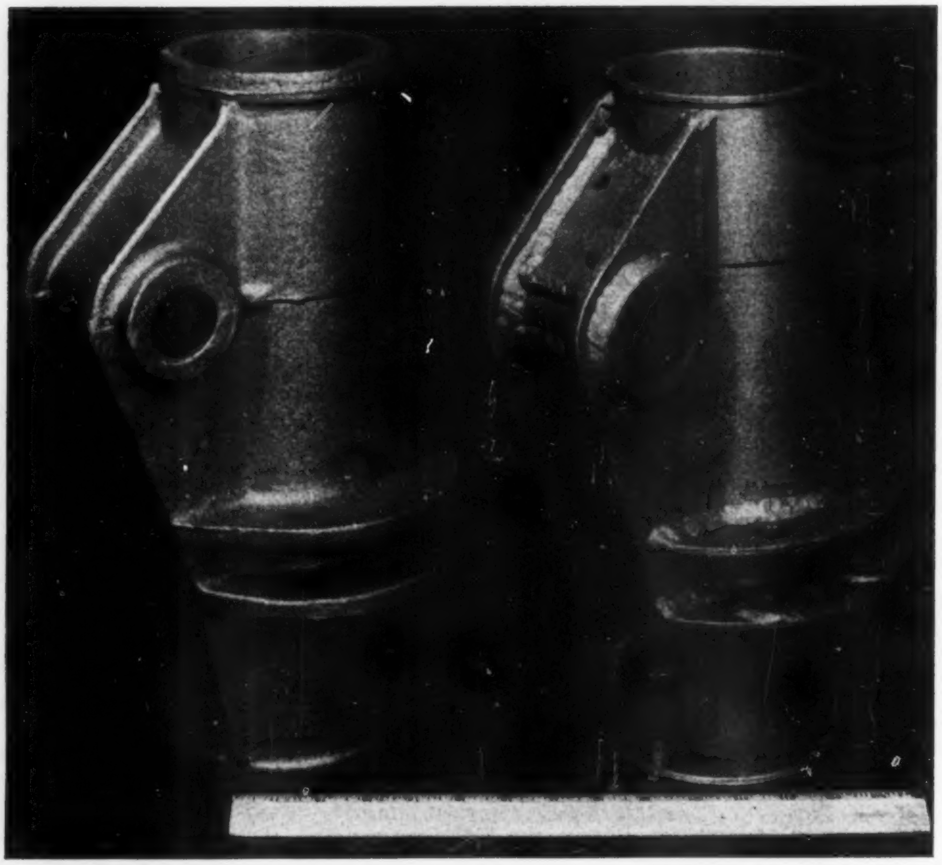

Fig. 4 — Centrifugal Casting Replaces Welded Landing-Gear Pivot for B-24 Bomber

assemblies, as illustrated in Fig. 2, a 75-mm. gun-recoil cylinder.

Steel castings were widely substituted for forgings during the war. With the greater freedom of design provided by casting, many such applications will doubtless be permanent. An outstanding example of this substitution is the manufacture of cast armor-piercing shells such as the 155-mm. shell (Fig. 1). Lack of forging capacity at the beginning of the war and inability to get the shells in the time required led to painstaking research backed by confidence in casting methods. Trial and error led to encouraging improvements, particularly during the early stage. The resulting cast shells have proven superior to forgings of similar type; the fundamental reason for this performance, no doubt, is to be found in the freedom from directional properties inherent in castings.

Figure 1, showing two shells which were fired through a 3-in. plate set at a 35° angle, is proof of their performance. Another less spectacular, although equally useful, task set for the steel

Fig. 5 — Complicated Internal Cores Required for These Spindle and Ball Sockets, Cast by Semicentrifugal Method, for Four-Wheel Drive Trucks

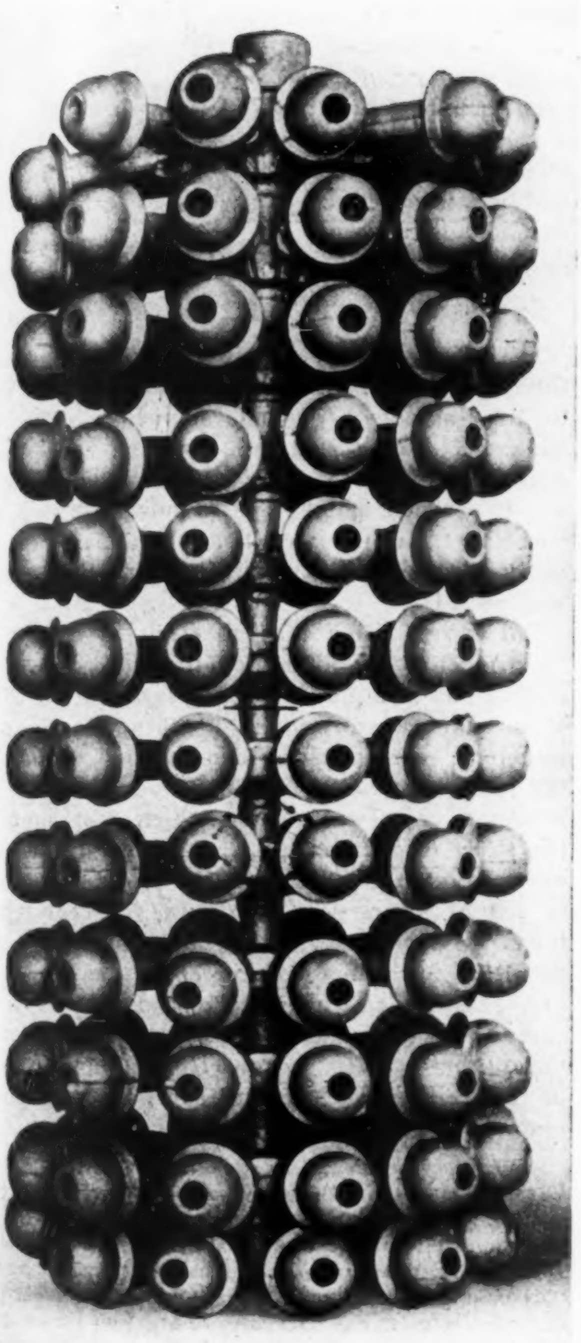

Fig. 6 — Nest of Spring Bearings for Tractor Tread Carriers; Casting Is Done by Centrifuging

foundry was the production of mortar shells — hollow projectiles made by the million — cast frequently 16 or more in a single mold.

Another vital part which was made by casting because of lack of forging facilities in the early stages of the war is the crankshaft for the Ford 575-hp. tank engine. This engine was adopted as standard for the 30-ton medium tank and over 20,000 of these castings gave satisfactory service on the battlefronts of the world. Indicating the extent of inspection methods applied in the modern foundry, this particular crankshaft is not only X-rayed 100% prior to acceptance in the machine shop, but is also magnafluxed at three different stages during machining operations.

A landing-gear shock strut used in one of our best-known carrier fighter planes further illustrates substitution of castings for forgings. Lightness, strength, reliability — all are paramount requirements.

The vastly increased requirements of the aircraft industry for materials and parts suitable for operation at high temperature have led to some interesting castings. For instance, a nozzle-box diaphragm used in an aircraft engine supercharger was previously fabricated of numerous parts, necessitating a considerable amount of welding. Welded construction of this diaphragm is shown in Fig. 3, and cast construction described in the caption.

Special Casting Methods — A discussion of developments in the ferrous casting industries would not be complete without touching upon the numerous special casting techniques which are finding ever-increasing applications.

The most notable of these is doubtless the utilization of centrifugal force by rotating the mold at suitable speeds. This method has three variations: true centrifugal casting, in which the part to be made is spun around its own axis; semicentrifugal, in which the part is also spun around its own axis but a core of some nature is used to form the inside contour; and centrifuging, which consists of grouping the parts more or less in balance around an independent central axis. All three methods have been used extensively in both gray iron and steel foundries.

Perhaps the most outstanding development utilizing the true centrifugal method is the manufacture of large-caliber guns. This was concisely described by the Editor of *Metal Progress* in "Critical Points" for July 1945, after a visit to Dickson gun plant near Houston, Texas. Other important ordnance parts made in this way are cylinder barrels for aircraft engines (for which an elaborate conveyerized casting machine was installed) and landing-gear hinge pivots for bombers (Fig. 4).

Applications of the semicentrifugal method have been found in the manufacture of a large number of parts such as the spindle and ball sockets for four-wheel drive trucks and sprockets for medium tanks as well as light armored cars (Fig. 5). An example of a centrifuge casting is the spring bearing for universal carriers (Fig. 6).

Precision Castings — One of the most interesting adaptations of previously known methods from the viewpoint of future possibilities is in the field of precision casting. The so-called "lost-wax" method which forms the basis for this work has been lost and found several times in the last few hundred years, with the first record dating back to the 16th century. Prior to the war, the process was used extensively by the dental profession and to some extent by manufacturing jewelers. With the steadily increasing requirements for new alloys and materials, many of which are almost impossible to machine, a new field of application was found for precision casting. Typical examples of parts made today are supercharger buckets of chromium-cobalt-tungsten alloys. The method was described in detail, with many photographs, by Arthur E. Focke in September 1945 *Metal Progress.* Perhaps of more far-reaching importance is the ability to cast intricate high speed steel tools such as cutters, reamers, and drills to such close limits that only the cutting edges need grinding before use. Figure 7 shows such tools cast by the lost-wax method.

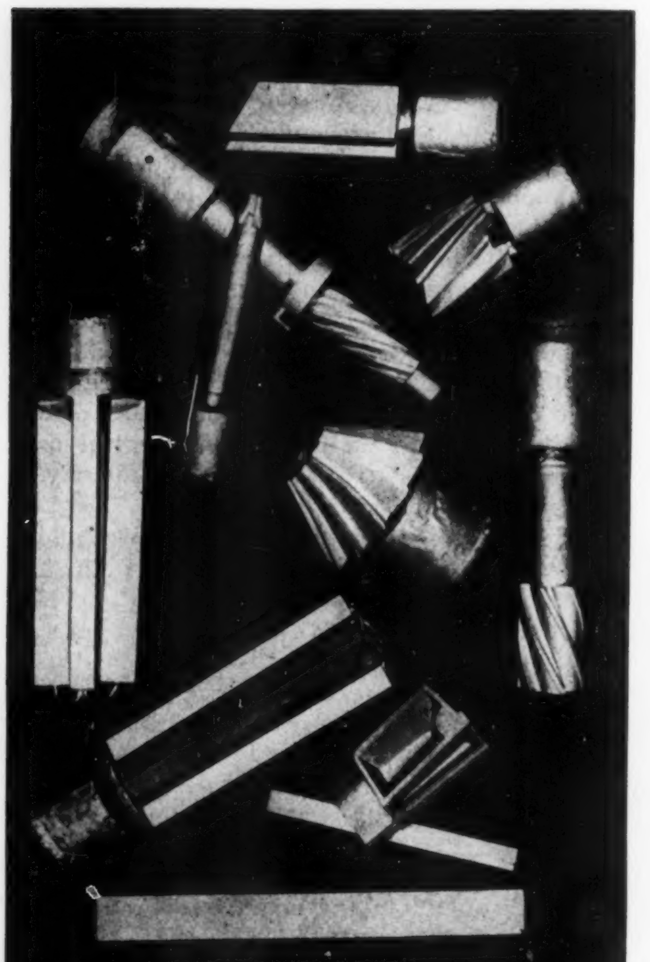

Fig. 7 — Various Cutting Tools Manufactured by Lost-Wax Method of Molding and Casting

It might also be mentioned that considerable attention is also being directed toward vacuum and pressure methods of casting in both steel and iron foundries.

Conclusions

The examples given in this article and its forerunner published last month have reviewed the most notable wartime developments in the iron and steel casting industry, and the effect these developments have had on present-day practice.

Experience gained by foundries during the war and their increased fields of activity should result in greater utilization of castings in the post-war period.

The realization that all steels originally are cast, and that the difference, therefore, between a casting and a forging is largely based on the effect of mechanical working in breaking up the cast structure, increasing the density and minimizing the effect of nonmetallic inclusions, has focused attention on new methods which will simulate the effect of mechanical working by introducing external or other forces on the casting that help to reduce grain size, minimize the tendency toward shrinkage, and in general increase the density. Such methods as centrifugal, vacuum and pressure casting have already found widespread application and are bringing us nearer to the ultimate goal — namely, equivalent properties in the finished part regardless of the method of manufacture used.

EDITOR'S FOOTNOTE ON GERMAN PRACTICE — M. T. Ganzauge and C. T. Briggs examined the German steel casting industry in 1945 (see *The Foundry*, April 1946) and reported that it was at about the U. S. level of 1935, as far as equipment and metallurgical technique was concerned, although the quality of the steel produced — largely electric and converter — was quite adequate for the parts made. Surface of castings was poor; foundries were forced to use sands obtainable nearby and synthesize a mixture as best they might. Advanced practices were noted as follows: 1. Almost universal use of core blowing machines and rubber lined core boxes. 2. Casting of shells, point down, in solid cast iron permanent molds (like an ingot mold) with cores and pouring basin made of core sand. 3. Centrifugal casting of gun tubes: A water-jacketed mold of Cr-Mo steel plate was rotated at high speed. Down the axis of this was thrust a slotted pipe filled with preheated fine silica sand, and enough sand dumped by turning the pipe to form a lining 0.10 in. thick. The mold was then tilted 5°, and a weighed amount of hot steel poured into its mouth. Life of the molds was 500 to 2000 casts.

By The Editor

Critical Points

IT WOULD BE nice to go around the beautiful new Cleveland laboratory of the Aluminum Co. of America with LOUIS KEMPF at the same time he was showing its equipment and conveniences to ZAY JEFFRIES and BOB ARCHER, his former associates. That team of men worked together for years and developed many of the strong casting alloys and heat treatments now widely used. They would undoubtedly contrast the spaciousness — magnificence even — of the present building and its wealth of special equipment with the facilities they enjoyed in the '20's. Imagine an experimental foundry two stories high, with melting furnaces under huge hoods and powerful exhausts (no trace of smoke or dust), with tiled floors swept and mopped nightly, with south exposure solidly glazed with blue actinic glass! Corridors tastily decorated in pastel shades! A heat treatment laboratory with rows of pit furnaces, quenching tanks and aging furnaces gleaming like a modern hotel kitchen and smelling just as good! Special rooms for special testing machines! Engine test blocks in sound-proofed cubicles, operated by remote control! Three radiographic rooms for parts large and small, arranged around a central dark room and viewing room! Wonderful equipment with wonderful opportunities for production! . . . .

A Modern Research Laboratory

This Cleveland laboratory is responsible for two of the many subdivisions of research work undertaken by Alcoa. One, under general direction of KENT VAN HORN, past president, devotes itself to foundry and forge plant alloys and practices, whereas the other devotes itself to the improvement of the product and the development of new uses (really a part of the Development Division, headed by FRANK JARDINE). As an illustration of the first class of problems could be cited an extended study of foundry and core sands that has devised proper formulas for synthetic sands, now standardized for use in Alcoa foundries. As an illustration of the second class of problems, take the stress analysis laboratory that studies completed castings or forgings received from customers; especially interesting is work on high speed machinery parts, painted with Stresscoat, spun in an evacuated whirl pit, and locations of high stress and dangerous fatigue areas spotted by the crazing of the brittle coating. (The right Stresscoat — for there are several modifications — when properly applied and expertly interpreted, can give a good idea of the *magnitude* of the overstress, but is especially valuable in fixing the exact place to put precise strain gages for quantitative studies.) Finally, the problem of new uses can be illustrated by the extensive work on gas engines with engine block and cylinder head of alloy formulated from aircraft scrap, pistons and connecting rods of alloys especially suited for those services.

All-Aluminum Gas Engines

Aluminum's light weight, better thermal efficiency, and improved characteristics of gas combustion have, in the past, been overbalanced by the necessity of a hard cylinder liner and the greater cost of aluminum over alloy iron. Today, with labor costs in the machine shop at ceiling and above, the superior machinability of the aluminum block bids fair to wipe out that differential. Another achievement of the development laboratory that is accomplished rather than hoped for is the much publicized piano frame made of aluminum. This has been accepted by piano manufacturers so readily because the full-sized self-supporting aluminum frame weighs 110 lb. and can be handled and strung by one workman; the conventional — nay, historic — cast-iron frame weighs about 200 lb. and requires two workmen to man-handle.

TO ADAPT my favorite hackneyed clause to the situation: "The Alcoa laboratory reminds me of the metallurgical department of the National Bureau of Standards — it is so different." Also it makes me think of the time, near the end of World War I, when I changed my engineering job for an editorial post with McGraw-Hill, and I visited the late Prof. JOSEPH W. RICHARDS at Lehigh University. At that time he had one of the famous names

in American metallurgy, was an international authority on aluminum, and was a most honored teacher. Imagine my disappointment, therefore, to find his laboratory in a dark basement, consisting of some benches, an anvil, a few piles of firebrick, and some rusty furnace shells — antiques even for those antiquated days. Such Raggedy-Ann handicaps to technical education and scientific research — and, believe me, they still exist! — always come to mind when inspecting the roomy, spick-and-span, shiny laboratories and workshops that have been built during World War II and financed by the inexhaustible resources of the War Department. . . . .

A Run-Down Research Laboratory

Regret that we have millions for the arts of war but only pennies for the sciences of peace is again the principal reaction of a visit to the famous metallurgical division of the National Bureau of Standards in Washington. Regret — but also amazement that so much good work has been produced with such poverty-stricken, down-at-the-heel, cluttered installations. Nothing, it is sure, could give a greater lift to the morale of the men in that institution than a good house cleaning (or even a first-class fire) that would clear away the accumulated junk — if only we could be sure it would be replaced with equipment worthy of the men and their responsibilities! . . . . Fair words are now being spoken by eminent scientists and engineers about the bill pending in the Congress to establish a National Science Foundation, "an active partnership between government and science". One must be rather optimistic to believe that future Congresses will be more liberal in financing the Science Foundation than the old ones have been in financing the Bureau. When we labor to provide measures that will prevent political log rolling from interfering with scientific research, let us also remember that financial neglect is almost equally a blight.

INTRIGUED by the report — perhaps erroneous — that the Maritime Commission had issued body armor made of plastic to lifeboat crews. Plastic plates instead of tough manganese steel! So got the truth from Col. RENE R. STUDLER in the research and development service of the Army Ordnance Department, who told me about the changes in "flak suits" for aviators, and the armored vests produced in large numbers for ground troops toward the end of the war. . . . . "Plastics" are indeed used to a great extent, but in the form of multiple layers of heavy nylon duck — the modern prototype of the ancient quilted armor. This quilting is between plates of metal (cut in 3 by 5-in. oblongs and sewed into a system of overlapping pockets in a canvas jacket) and the soldier's heavy clothing, which in itself lends considerable aid to the nylon layers in slowing down or trapping small, sharp, jagged fragments. Metal plates were originally of Hadfield's manganese steel, 0.045 in. thick, but an equal weight of 24S-T aluminum alloy was found much superior in resistance to shell fragments. Finally aluminum alloy 75S-T was adopted as standard, because the "punchings" produced by sub-fatal penetrations were more regular in shape and did not knife their way through the quilting into the soldier's body. The early manganese steel vest (front and back) had 3.8 sq.ft. area and weighed 17 lb. 6 oz.; the most recent 75S-T aluminum nylon vest (front and back) covers about 50% more area, weighs less (16 lb. 15 oz.) and has approximately equal resistance to fragments. . . . . No soldier can carry around enough protection to stop a rifle bullet or similar high speed projectile, but statistics show that less than 20% of battle casualties are from bullets — soldiers in action are hit by shell fragments. The first problem tackled by the armorers was to protect aviators from fragments of antiaircraft, or 20-mm. high explosive shells fired by German fighter planes and exploding on contact with the fuselage. On the average, to produce a casualty, the fragment will weigh about 0.05 oz. and travel at about 2500 ft. per sec. when it reaches the aviator. On averages, this is the fragment that does the preventable damage, and this must be stopped by armor. . . . . Relative merit of an armor combination is measured in the ingenious "20-mm. triangular fragmentation test". Equipment consists of three long, tunnel-like boxes, laid out at 120° each to each, with open ends facing a common center at which is suspended a 20-mm. high explosive shell. Over the open ends are placed identical samples of armor to be tested. Behind the samples, fixed into the boxes normal to the axes, at regular spacings, are frames holding stretched aluminum sheets which separate each tunnel into a series of compartments or zones. After the shell is exploded, the tunnels are opened and the fragments in each zone are weighed. Summation of weights multiplied by the number of zones penetrated gives a merit figure for the armor under test, which is a measure of the casualty-producing ability of the fragments *after* penetration of the armor. This, in effect, gives a direct measurement of the rela-

Aluminum for Body Armor

"Behind the Sample" Evaluation

tive efficiency of different types of armor in preventing deaths and reducing the seriousness of wounds — for obviously, only the fragments that get through the armor can cause injury. . . . . This "behind the sample" evaluation has paid large dividends in saving the lives of American soldiers. Records of the Eighth Army Air Force, covering 758 men struck by enemy missiles, show a reduction of 80% in expected wounds and 50% in certain deaths avoided when body armor was worn.

SINCE most good ideas come from others, let me pass along the following quotation from the *La Salle Washington Letter* which HAROLD K. HOWE sends occasionally to his friends and customers: "The Lord's Prayer contains 71 words, Lincoln's Gettysburg Address some 267, and the creation of the world is described in Genesis in about 800 words, but recently it took the O.P.A. 2500 to raise the price of cabbage seeds 1¢ per lb." Wonder where HAROLD heard that one!

The Russian Plan for Atomic Control

MR. BARUCH, United States member, proposed to the United Nations Atomic Energy Commission the establishment of an International Atomic Authority (much as developed in the State Department's pamphlet abstracted in *Metal Progress* for May, page 992, and which should be studied when making any appraisal of alternative plans). This provides that the countries which developed the bomb would gradually turn over to the Authority their scientific and technical information as well as their stocks of fissionable materials and completed bombs and manufacturing plants as soon as it is apparent that the control system is adequate and proper, and enforceable penalties for violation have been established. A fundamental part of the plan is that no part of these operations may be blocked by veto of any nation. President TRUMAN, in a press conference, said later that Mr. BARUCH's proposals represented the policy and aims of the U. S. Government.

Representatives of United Kingdom, Canada, China, Mexico and Brazil formally approved the American plan as a basis for discussion.

ANDREI GROMYKO, Russian member of the United Nations Atomic Energy Commission, in the course of a long address on June 19 made no reference to the American plan, but proposed an alternative "agreement to forbid the production and use of weapons based upon the use of atomic energy for the purposes of mass destruction, followed by other measures to set up a system of supervision and control to see that the agreements are observed, as well as sanctions against unlawful use of atomic energy. . . . . Besides this, it is indispensable that there should be an exchange of scientific information between countries and joint scientific efforts toward broadening the use of atomic energy to raise the material welfare of the people and develop science and culture".

To proceed with this plan Mr. GROMYKO proposed the appointment of two committees, one for the exchange of scientific discoveries connected with obtaining and using atomic energy, information about the technological processes used, the industrial production methods, and forms, sources and locations of necessary raw materials.

The second committee would draft agreements to outlaw atomic weapons and devise plans for their observance and enforcement. He emphasized that "the activity of the Commission for the Control of Atomic Energy can lead to the desired result only if it is in full conformity with the principles of the Charter of the United Nations, which are at the basis of the activity of the Security Council, because the Commission is an organ of this organization. Efforts made to undermine the activity of the Security Council, including efforts directed to undermine the unanimity of the members of the Security Council, are incompatible with the interests of the United Nations.★ I consider it necessary to make this statement in order that from the very beginning I might make clear the position of the Soviet Government."

Mr. GROMYKO outlined such a self-denying ordinance as might be prepared by the second proposed committee as follows:

"The high contracting parties solemnly declare that they will forbid the production and use of a weapon based upon the use of atomic energy, and with this in view, take upon themselves the following obligations: *(a)* Not to use, in any circumstances, an atomic weapon; *(b)* To forbid the production and keeping of a weapon based upon the use of atomic energy; *(c)* To destroy within a period of three months from the entry into force of this agreement all stocks of atomic energy weapons, whether in a finished or semi-finished condition.

"Any violation of this agreement shall constitute a serious crime against humanity, and the high contracting parties shall pass legislation providing severe punishment for violation.

"The agreement shall be of indefinite duration and open for signature of all States, whether or not they are members of the United Nations. It shall come into force after approval by the Security Council and after ratification by half of the signature States. After its entry into force, it shall be an obligation upon all States, whether members or not of the United Nations."

★Editor's Note—The Russians, therefore, insist on retaining the veto in future decisions on atomic matters.

By Given Brewer
Consulting Engineer
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Use of Stainless Steel as a Structural Material in Jet-Propelled Aircraft

In THE PAST airplanes built wholly from stainless steel have not proven to be as efficient as their duralumin counterparts. Stainless steel has not proven to be an efficient structural material in airframe construction for the following reasons: As the principal function of airframe skin is to carry shear, other things being the same, the same *weight* sheet of stainless steel will buckle at about one-third the stress that will cause duralumin sheet to buckle. Over the forward 30% of an airplane the drag is very seriously increased by even slight protuberances such as rivet heads and skin wrinkles, therefore a much greater weight in stainless steel skin is required to preserve smoothness of contour by providing sufficient thickness (bulk).

In the design of jet-propelled aircraft new problems have arisen that give a weight and strength advantage to the use of stainless steel for the rear two-thirds of the fuselage. Most contemporary aircraft of this sort house the jet engine within the fuselage, aft of the pilot. This inboard installation heats the fuselage skin to temperatures between 275 and 450° F. when the engine is operating, unless steps are taken to insulate and to cool the skin — procedures that are costly from the weight standpoint.

It has been found by A. E. Flanigan, L. F. Tedsen and J. E. Dorn at the University of California during a study of stress-rupture and creep at elevated temperature, and published as part XII of the "Final Report on the Study of the Forming Properties of Aluminum Alloy Sheet at Elevated Temperature" (Report W-216, N.R.C. No. 548, 1945) that the commonly used aluminum alloys are subject to the phenomenon of stress-rupture such that the breaking strength of the skin is very materially reduced if tested at temperature after operating at moderate temperatures for 1000 hr. Some data for alclad 24S-T and 24S-T81 are given in Fig. 1 wherein the plotted points were obtained during continuous heating and constant stress for the indicated periods of

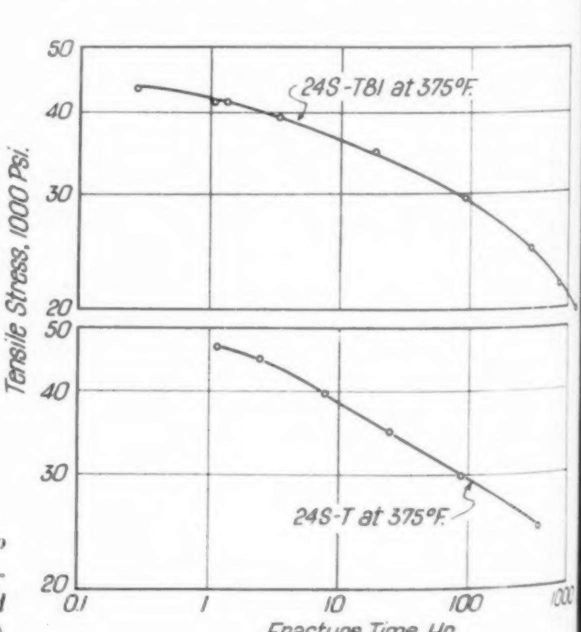


Fig. 1 — Log-Log Plot of Stress-Rupture of Two Alclad Alloys, Tested as 0.040-In. Sheet, Samples Cut Cross Grain (Flanigan, Tedsen and Dorn, Report W-216, N.R.C. No. 548, 1945)

Fig. 2 — Consolidated Vultee XP-81 Fighter, Speed More Than 500 Miles per Hr., Powered With General Electric TG-100 ("Propjet") Engine and Four-Blade, 12-Ft. Propeller in Nose, and G.E. I-40 Jet Engine in Rear. Exhaust of the front engine is directly under the pressurized cabin; exhaust of the rear engine is through the tail. Combined power is about equal to the four engines on a B-29 Superfortress. Some details of the I-40 engine are given in the article on superalloys for jets starting on page 97

time. Since the jet-propelled airplane operates for a few hours at most and then cools off, it might be questioned whether such interrupted service at high temperature is definitely harmful to the strength properties of these aluminum alloys that have been so successful under atmospheric conditions. However, the short time tensile properties of the aluminum alloys were also studied by Messrs. Flanigan, Tedsen and Dorn, and the drop in strength with temperature is roughly parallel to the curves in Fig. 1. Since the operation of the jet fuselage is probably somewhere between a condition of steady stress and a condition of maximum load, both the stress-rupture and the short time tensile stresses are important. Knowing that lowered values of both stresses occur at the temperatures encountered in operation, it becomes mandatory to insulate and cool the fuselage structure if it is to be made of duralumin. The extra weight of such apparatus permits the reconsideration of stainless steel, which is not weakened until *very* high temperatures are reached.

Basically, stainless steel has the same strength-to-weight ratio as duralumin, as shown in Table I; it is only the buckling characteristics of stainless that rule against its use. If buckling can be permitted, then stainless steel will carry as much shear for the same weight structure. It so happens that the boundary layer (the layer of air adjacent to the skin moving at a speed less than the free stream velocity — essentially stagnant air) is only a few thousandths of an inch thick at the front of the airplane, but the layer has increased to about 3 in. thick at midlength

Table I — Comparison of Physical Properties of 18-8 and Duralumin

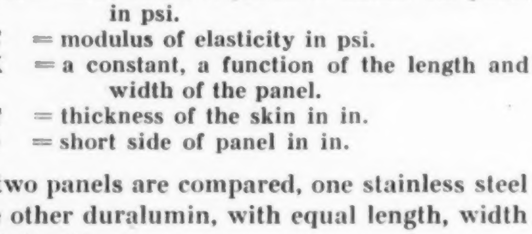
	F_{ty} (0.002 In.) Tensile Yield	F_{tu} Ultimate Tensile Strength	F_{su} Ultimate Shear	$\frac{E}{10^6}$	Density Lb./In.^{3}	$\frac{F_{tu}}{\text{Density}}$
18-8, full hard	160,000	185,000	100,000	27	0.286	6.47×10^5
24S-T alclad	39,000	59,000	36,000	10	0.100	5.9×10^5
24S-T86 alclad	62,000	66,000	38,000	10	0.100	6.6×10^5

of the fuselage, and to 4 in. at the tail cone on a typical jet fighter. It is apparent, then, that wrinkles in the fuselage over the latter two-thirds of its length will not appreciably alter the drag of such an airplane, particularly if these wrinkles only occur during severe maneuvers and not in steady, level flight.

Due to the conditions enumerated that favor the use of stainless steel, it was the author's suggestion that this material be considered for the aft two-thirds of the fuselage and (following this suggestion) it has been possible in one jet fighter to achieve a 20% weight saving over duralumin by using stainless skin, bulkheads, and stiffeners for the portion of the fuselage from the pilot's seat aft.

This is an application of modern metals to modern machines that requires the combined experience and information of various specialists in order to arrive at a correct decision. Management will not only ask metallurgists about the properties of the various materials, but also the design engineers and the stress analysts about the loads these materials must carry. In order to understand some of the answers the stress analysts will give, and in order to support some of the statements made, let us consider in some detail the buckling resistance of sheet metal. According to the first chapter in publication ANC-5 of the Army-Navy-Civil Committee on Aircraft Design Criteria ("Strength of Aircraft Elements") the formula for buckling stress in shear is:

$$F_{scr} = KE(t/b)^2$$



where F_{scr} = shear stress required to buckle the panel in psi.
E = modulus of elasticity in psi.
K = a constant, a function of the length and width of the panel.
t = thickness of the skin in in.
b = short side of panel in in.

If two panels are compared, one stainless steel and the other duralumin, with equal length, width and weight, then:

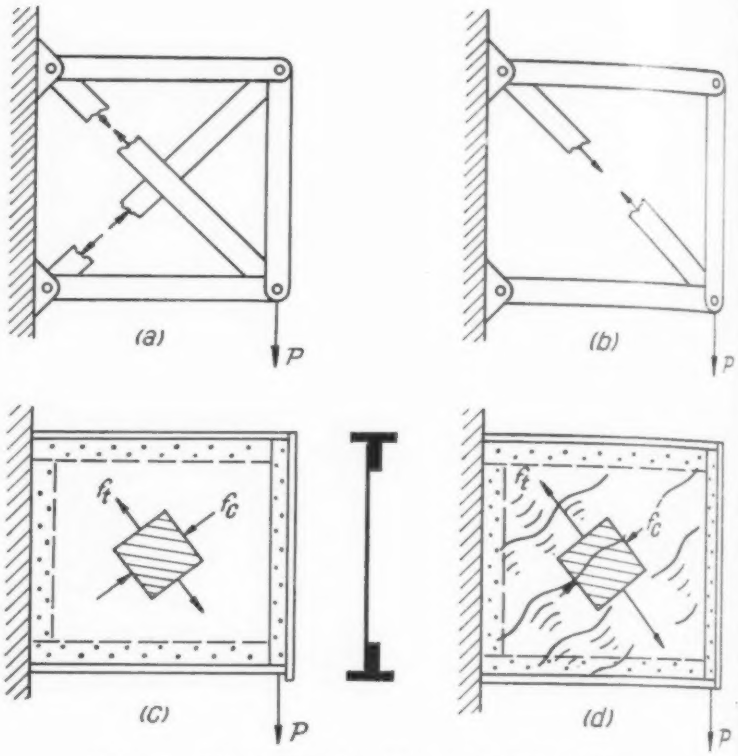


Fig. 3 — Sketch Showing Manner in Which Truss and Sheet Metal Panels Resist Shear Analogously

$$F_{scr} \text{ (for steel)} = K \cdot 27 \times 10^6 (t/2.86b)^2 \quad (1)$$
$$F_{scr} \text{ (for duralumin)} = K \cdot 10 \times 10^6 (t/b)^2 \quad (2)$$
$$\frac{(1)}{(2)} = 0.33 \quad (3)$$

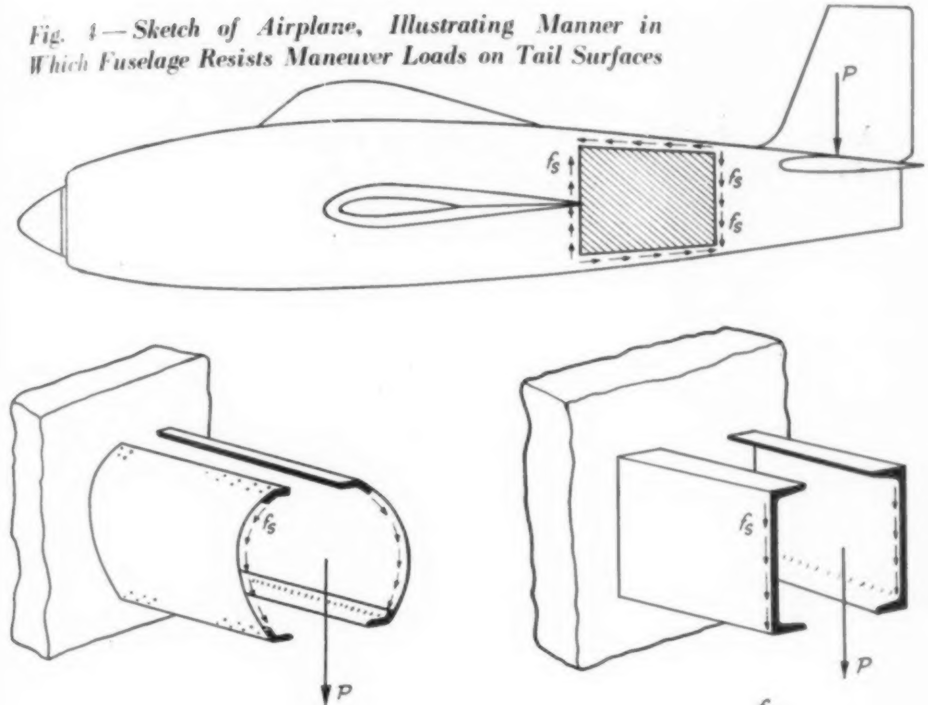
The buckling strength of the stainless steel panel then is shown to be only one-third that of a duralumin panel of equal size and weight.

The manner in which a sheet metal panel resists shear may be likened to an X-frame truss, as shown in Fig. 3*(a)*. The vertical shear load *P* applied to the X-truss produces a tensile load in one diagonal and a compression load in the other. If both diagonals have the same rigidity the induced loads will be equal. Similarly, if a thick sheet — as shown in Fig. 3*(c)* — is loaded by a vertical load *P* and it does not buckle, equal compression and tensile stresses will exist, as shown in the sketch.

However, if the shear panel is made of thin sheet and the stress is such as to cause buckling, then the panel can still resist the load by diagonal tension as shown in sketch *(d)*. A sheet metal panel resisting shear by diagonal tension is analogous to a frame such as shown in Fig. 3*(b)*, wherein only the tension diagonal exists and it must carry the entire shear load, namely, $P\sqrt{2}$.

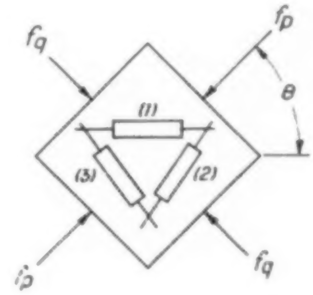
If it is permissible that a shear panel buckle, then the strength of two panel materials may be compared not on the basis of their buckling resist-

Fig. 4 — *Sketch of Airplane, Illustrating Manner in Which Fuselage Resists Maneuver Loads on Tail Surfaces*



ance but almost solely on their ultimate tensile strength. On the latter basis it can be seen from Table I that 18-8 should theoretically carry as much shear load for the same weight as an equivalent duralumin panel.

It was stated in the early part of this article that the function of the skin of an airframe is solely that of carrying shear. This may be illustrated by Fig. 4. A section of fuselage skin has been hatched for identification, and isolated (at left, below) so that the forces acting upon this section of the fuselage may be investigated. If the pilot initiates a maneuver such that a down load *P* acts on the horizontal tail surfaces, then this force causes the airplane to rotate about some axis about 30% aft of the wing leading edge. The load *P* is resisted by the polar moment of inertia of the fuselage mass, producing shear in the fuselage skin, and bending in the form of axial loads in the thick caps or stringers within the fuselage (see Fig. 4). It can be seen that the fuselage then acts like a box beam with curved webs, analogous to two cantilevered channel beams in a bridge or building.



To validate the theoretical considerations presented, a full-size stainless steel shear panel similar to that shown hatched in Fig. 4 was constructed of 0.016-in. sheet. This is shown in Fig. 5, page 88. It was fixed solidly along its left edge, loaded by a jack under its lower right corner and the stresses acting at many points were determined. For our present discussion we are mostly interested in the stresses at the midpoint of the web; these were measured by means of two equilateral electric strain gage rosettes (as shown in the sketch at left) mounted back to back on the inside and outside of the cover sheet. Readings of the two rosettes were averaged to eliminate the effect of buckling; data are tabulated in Table II, below. From the data obtained and plotted in Fig. 6 (page 88) it can be shown that the panel

Table II — Strain Gage Data Obtained From Stainless Steel Shear Panel Under Various Loads

Factor†	1000 Lb.	2000 Lb.	5000 Lb.	10,000* Lb.	12,500 Lb.
e_1	−2.5	−46.5	+130	+366.5	+617.5
e_2	+77	+160.5	+701	+1,451	+1,615
e_3	−69.5	−126.5	−224.5	−371.5	−619
f_p	+1800	+3470	+19,600	+41,700	+50,000
f_q	−1630	−3600	−3,000	−2,500	−4,200
θ	46½°	53°	48½°	47½°	43½°
$f_{s(x-y)}$	1715	3400	11,200	22,000	26,800
$\frac{P}{ht}$	2400	4800	12,000	24,000	30,000

*Double amplitude of wrinkles = ¼ in.

†where E = 27.5×10^6 psi.
f_p = major principal stress, psi.
f_q = minor principal stress, psi.
e_n = average axial strain, micro in./in. along axis of strain gage n.
θ = angle between f_p and axis of strain gage No. 1.
$f_{s(x-y)}$ = shear stress parallel to *X* or *Y* axis in shear panel, psi.
P = vertical shear load applied to shear panel, lb.
h = height of shear panel projected, in.
t = skin thickness of shear panel, in.

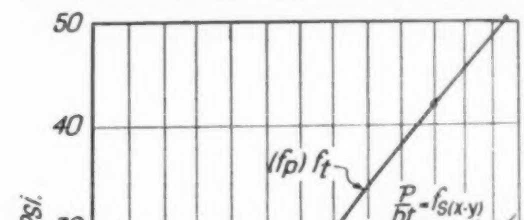
Fig. 5 — Shear Panel of 18-8 Under Buckling Load (by Jack, Lifting at Lower Right Corner)

carries 84% of the applied shear by diagonal tension at a load of 12,500 lb. The panel broke when carrying a shear load of 18,000 lb., yet if buckling were *not* permissible this panel could only have carried 2000 lb. vertical shear load.

According to a private communication from V. N. Krivobok the behavior of several commonly used stainless steels in various tempers at moderate temperatures has been investigated and will soon be available in published form. Some data are presented on the high temperature stress-rupture properties of stainless steel in C. T. Evans's article on "Wrought Heat Resisting Alloys for Gas Turbine Service" in *Metal Progress* last November, although the temperatures investigated are much higher than the moderate ones endured in aircraft fuselages.

Some other related information on strength properties is contained in an article by R. R. Kennedy on "Creep Characteristics of Aluminum Alloys" in *Proceedings* of the American Society for Testing Materials for 1935, and in Circular C-447 of the National Bureau of Standards ("Mechanical Properties of Metals and Alloys", 1943 edition).

Fig. 6 — Principal Stresses Measured on Stainless Steel Shear Panel; Notation as in Table II



Bits & Pieces

Pick-Up for Tiny Parts

ANOTHER industrial use for sponge rubber may solve assembly problems in plants other than the one where it was first successfully installed.

Employees were having difficulty picking up the small subassemblies and even smaller metal parts. The belt traveled past them faster than they could pick up the parts, but not faster than they could work. The chief trouble was that the girls fumbled the tiny parts and couldn't get them off the table at the speed necessary to keep up with the production line.

We suggested that the traveling table be covered with a thin slab of sponge rubber. It

worked. The sponge rubber slab was ⅛ in. thick; the girls could get their fingers into it far enough to pick up the smallest parts. (A. M. FIALA, The B. F. Goodrich Co.)

Special Alloys for Gun Synchronizer

IN THE DESIGN of the Fairchild electronic synchronizer for airborne guns, which times the firing of three 0.50-caliber machine guns and provides safe passage for the bullets through a three-bladed propeller rotating at speeds from 800 to 1500 r.p.m., we made good use of two alloys entirely new to us and perhaps to most manufacturers. These alloys were "KR-Monel" and, particularly, "Hiperco", and were used in the trigger-motor armature and the trigger-motor center core, respectively.

After experimenting with several metals for the armature, we came to a dead end because we could find none that would meet the over-all specifications of light weight, high strength, high resistivity, nonmagnetic properties, heat treatable to Rockwell C-38, yet machinable and ductile enough for cold work. The nonmagnetic specification was particularly important because the armature must operate between the poles of a powerful electromagnet. High electrical resistivity was also essential because the operation of the synchronizer induces a relatively high surge voltage in the armature, and if the resistance were not high, excessive power would be lost due to induced eddy-currents. Further, the metal had to resist corrosion, scaling, fatigue, and warpage in jungle heat and stratosphere cold.

The alloy meeting all these specifications was found to be KR-Monel, a variety of the age hardenable alloy that is slightly higher in carbon and more readily machinable than K-Monel. Besides overcoming obstacles encountered with previously tested metals, it achieves lightness and economy of space because of its great strength; as is shown in the accompanying view the armature is made with thin perforated sections and still retains rigidity. Incidentally, although the wall of the armature is only 0.013 in. thick, the armature delivers a "punch" of 50 lb.

In the trigger-motor center core, Hiperco was put to one of its first commercial uses. A product of Westinghouse Electric Corp., this alloy consists of approximately one-third cobalt, two-thirds iron, and 1 to 2% of another element to increase the electrical resistivity. (This alloy is not to be confused with cobalt permanent magnet steel.) We found in it the solution to our main design problem here, namely, the reduction of over-all size.

A Machine Gun Synchronizer Part Made of a Special Monel Metal

With two coils surrounding it, this center core is in a strategic position in the assembly, as its size determines the relative sizes of the coils and the outer magnetic shell. It takes the form of a small spool. Hiperco can be operated at a higher magnetic flux density than other available alloys and thus permits a smaller diameter core for the same force. The over-all cumulative effect gives a reduction in weight of about 25%, besides a reduction in size and power consumption. Since every possible expedient has to be taken to limit the size of the core, Hiperco is ideal for this part, bringing about required reduction in volume without reducing its ability to carry the necessary magnetic flux. (HERBERT C. ROTERS, director of research, Fairchild Camera & Instrument Corp.)

Mechanized Mold Preparation

THREE big-end-down 23½ by 26½ by 80-in. ingot molds can be water dipped and pitch coated every 2 min. in the new set-up at the National Works plant of National Tube Co. This new system, shown in the photograph, uses less than half a pound of prepared coal tar pitch per ton of ingots.

The operations consist of picking up three hot (300 to 500° F.) molds by a special lifting rig and 15-ton yard crane, dipping the set into a water tank to remove any dirt, and lowering them on the spray platform. The mold lifter is lowered until the cover plate, suspended by chains within the framework of the lifter, rests on top of the

molds. Compressed air then blows in the powdered coal tar pitch through three conical depressions centered under the molds in the base of the platform. The cover plate keeps all but a small part of the pitch from escaping.

A uniform mold coating from top to bottom is obtained with 90-lb. air pressure. At this pressure only 5 sec. is required for sufficient pitch to be siphoned through 2-in. pipe into the mold. Exact control of the flow to each of the three molds is obtained through push button and a motor operated cam arrangement that opens three quick-acting air valves, one at a time, for 5 sec. each. Individual operation of any of the three blasts can be secured by depressing the valves by hand as desired.

As soon as the third mold has been coated, the crane picks up the set of three and returns them to their positions on the ingot buggy, the stools having been blown clean while the molds are being sprayed.

Air is blown into the bottom of the containing hopper to agitate the powdered pitch, which otherwise tends to pack, and assures a constant supply of powder to the suction line. A screen just above the suction intake removes lumps that might clog the system.

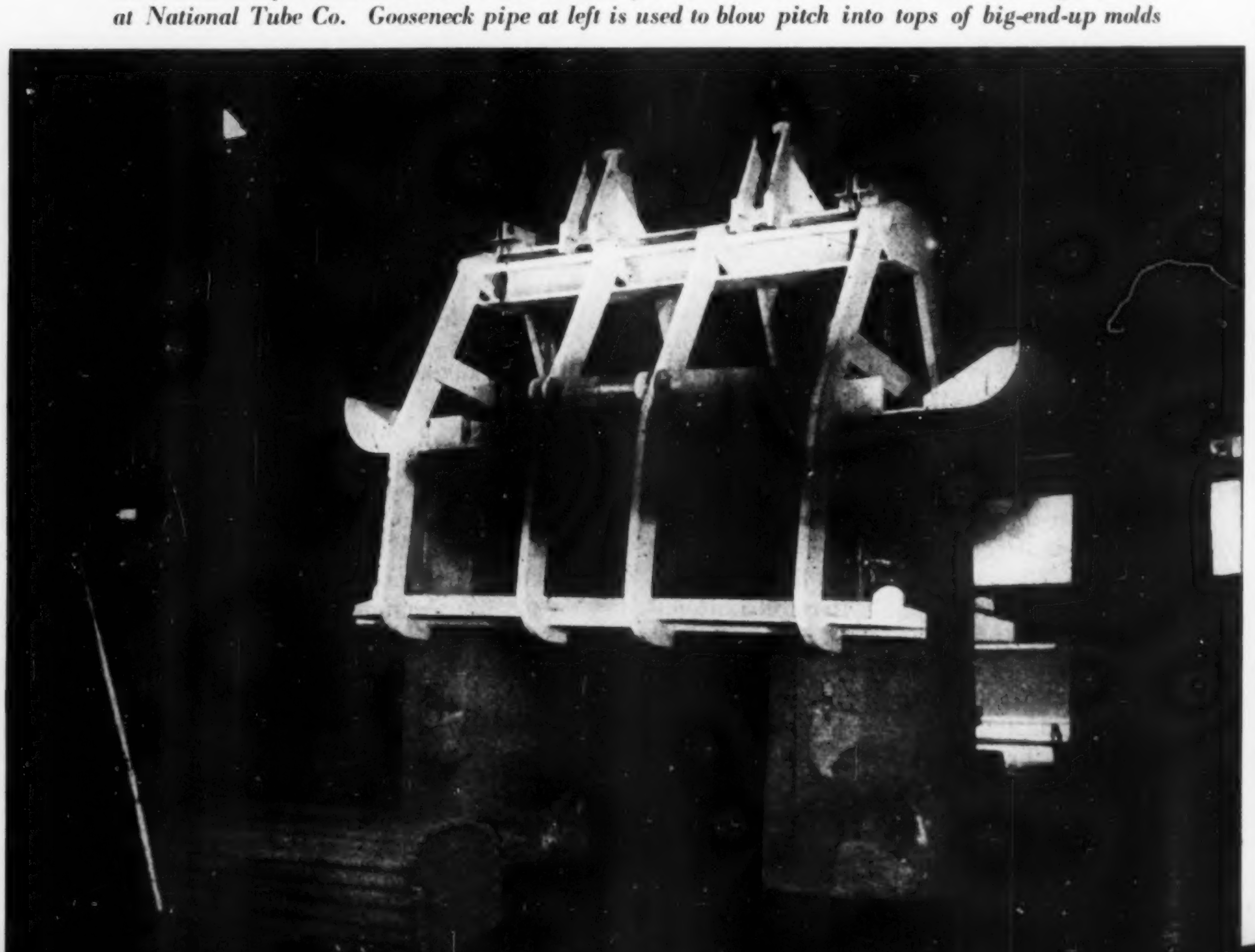
Provision is also made to prepare big-end-up molds (closed bottoms) by a hand spray, also connected to the pitch hopper. Washed molds are suspended over the coating platform and a gooseneck spray pipe (shown at left of the photograph) with a cone-shaped nozzle is inserted between the cover plate and the mold. A foot pedal controls the compressed air valve on siphon and hopper, and the shape of the nozzle distributes the pitch evenly over the mold walls.

Experience shows a very substantial decrease in billet scrap and scarfing required since the new mold preparation system was placed in operation. The coating is considered superior to any previously secured with tar, fuel oil, graphite or brine. (A. W. THORNTON, superintendent, openhearth and bessemer department, National Tube Co.)

To Remove Passive Film When Etching

WHEN polishing metallographic specimens time and work are saved if two or more specimens are mounted together in the same holder. However, difficulty may be had in etching steel specimens so mounted. Polished steel specimens sometimes acquire a passive film if they are not etched soon after polishing. This passive film makes one specimen etch differently from the others in the same mount — one doesn't etch while the others do, or it doesn't etch as quickly.

Central Mold of Three Removed to Show Blast of Fine Coal Tar Pitch Used to Coat Ingot Molds at National Tube Co. Gooseneck pipe at left is used to blow pitch into tops of big-end-up molds

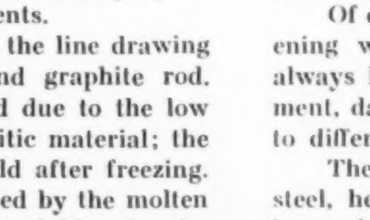


This difficulty is generally eliminated by repolishing the specimens lightly on the final polishing wheel immediately before etching. Another method is to dip the specimen alternately in the etching solution and under a stream of hot water. A third method is to rub the specimens lightly with a sharp scriber while in the etching solution. Only a light scratch is needed because an electrolytic cell is set up between the film and the iron which rapidly dissolves the film. (GERRIT DE VRIES, metallurgist, Dahlgren Naval Proving Ground.)

Graphite Molds for Casting Jominy Bars

THE Society of Automotive Engineers has recommended that certain steel castings meet Jominy end-quench hardenability specifications instead of the usual chemical and physical requirements. There are several methods of preparing such test specimens including *(a)* two-piece steel molds, *(b)* dry-sand molds with pyrex glass liners, *(c)* machining from a cast coupon. However, the cheapest and best casting can be made in a warm graphite mold. Either the full-length Jominy specimen can be cut from it, or the test button of the length determined by the hardenability specifications of the casting it represents.

Such a mold, as sketched in the line drawing below, is made of a 3-in. round graphite rod. No draft is required in the mold due to the low coefficient of expansion of graphitic material; the steel shrinks away from the mold after freezing. Inasmuch as graphite is not wetted by the molten metal there is no likelihood of sticking in the mold or any "burn-in". Carbon pick-up from the mold is negligible and there is no decarburized surface. For a perfect surface on the specimen, the mold should be preheated to 750° F.



Based on experience for a specimen 1½ in. long, the cost is as follows:

Four molds were purchased at \$3.00 each (\$1.50 in lots of 10). One sample is taken every half hour and the first mold was still in use after casting more than 100 samples, still in the original condition except that the diameter of the specimens gradually became 0.010 in. larger; hence this mold was discarded.

As can be seen this figure of from 1½ to 3¢ per sample for molding cannot be met by any other method. Perhaps if the use of these molds becomes popular one of the graphite manufacturers can undertake to produce them on a production scale.

Such molds can also be used in sizes for carbometer samples, standard test bars and for specimens for chemical analysis, as substitutes for the present steel or iron molds. (P. M. SANDERS, consultant in metallurgy, Detroit.)

Straightening of Warped Shafts

THE OLD "bugaboo" of heat treating — distortion of long shafts, drills, broaches after hardening — came around again recently in the form of a shaft, 5 in. round by 26 in. long, with only 0.027 in. grinding stock. It warped 0.046 in. during heat treatment.

Such items can sometimes be handled during the draw as follows: Heat the entire shaft to the draw temperature or slightly under and immerse it horizontally half way into water, maintaining heat on the high side while the low or concave side is cooling. If this is done in repetitive operations, the piece being entirely cooled before reheating, it may eventually straighten up to grinding limits.

Of course there is also the method of straightening while cold in a gagging press, but this always has appeared to be a rather brutal treatment, dangerous to hardened bars. So we turned to differential heating with oxy-acetylene flames.

The shaft in question was made of S.A.E. 4150 steel, heat treated to Rockwell C-40 to 41. We lowered the shaft horizontally, suspended from each end, into a tank of cool, circulating water, with the low or concave side down, the shaft being immersed only half way. We then applied heat to the high or convex side with an oxy-acetylene torch, being very careful not to exceed the draw temperature of the shaft which was 900° F. This temperature was gaged by a "Tempil stick", a crayon mark which melts at 875° F. The weight of the piece plus the differential in tensile strength of the hot and cold sides served to pull the ends upward. With five or six repeated heating operations in this manner we were able to bring the shaft "in" the required 0.019 to 0.020 in. One added precaution is that the entire piece is to be completely cooled between each heating operation. (THEODORE F. BURCH, President, Kentucky Steel Treating Co.)

By A. M. Hall
Research Engineer
Battelle Memorial Institute
Columbus, Ohio

Metallographic Etchant to Distinguish Oxidation in Steel

IN THE COURSE of research at Battelle Institute for the Office of Production Research and Development and other governmental agencies on the flash welding and pressure welding* of various steels, the metal at the weld line was often found to be inferior in mechanical properties. This could sometimes be attributed to the presence of visible oxides and decarburization, and sometimes to decarburization in the absence of visible oxides. Reduced mechanical properties, however, were often obtained even when the usual metallographic methods revealed no evidence of decarburization or oxides, or when decarburization was eradicated by suitable postweld heat treatment. This condition was surmised to be due to a definite but limited degree of oxidation, and much effort was expended to learn its true nature and eliminate it.

At about this time it was learned that the Menasco Mfg. Co. of Burbank, Calif., had been studying similar welding problems and had developed a metallographic etching technique for bringing out weld-line oxidation. This method was described by Leslie Fine in the January 1946 issue of *Metal Progress*, page 108, but it was not available at the time the Battelle research was under way. The metallographic approach was therefore pursued independently of the work done on the West Coast. More than 150 combinations of etching ingredients were tested on specimens of pressure welds and flash welds before satisfactory results were obtained. The etchant in final form was discovered to be similar in effect to that of the Menasco Mfg. Co., as described by Mr. Fine.

In early experiments efforts were made to produce the desired results by modifying existing reagents such as nital, picral, Stead's reagent, and Oberhoffer's etch. It was quickly surmised, however, that a strong oxidizing combination was required, strong enough to attack and stain all features of microstructure that were unoxidized or contained carbon, but which would leave oxides and oxidized regions unaffected. Oxidized localities would then be revealed by the contrast developed between their whiteness (smooth reflectivity) and the stain (roughness) on the surrounding material.

Preparation of the Reagent

An alkaline solution of potassium permanganate and potassium dichromate was found to accomplish this purpose. It is composed of 10 g. $KMnO_4$, 10 g. NaOH, 10 g. Na_2CO_3, and 4 g. $K_2Cr_2O_7$, dissolved in 100 ml. distilled water. For average metallographic specimens, best results have been obtained by immersing each specimen in 200 ml. of solution in a 600-ml. beaker. The solution is heated to boiling and the metallographic specimen is immersed polished-face upward. Boiling is continued until the polished surface has developed a brownish-blue to purple-blue tint. This is achieved in 10 to 40 min.; in general, the higher the carbon or carbide content of the material, the more rapidly will it etch. The specimen is then removed, washed in running water, rinsed in alcohol, and dried in a stream of clean air.

No special precautions are required in making

*"Evaluation of the Quality of Pressure Welded Joints in Alloy Steels, and the Ease of Production Control of the Process", by C. B. Voldrich and J. L. Zambrow, W.P.B. Research Project N.R.C.-558, W.P.B.-177, Battelle Memorial Institute, Aug. 31, 1945.

or handling the solution. The constituents need not be too accurately measured. The solution must, however, be used fresh.

Specimens are best handled unmounted, but if their size or shape will not permit this, they may be mounted in lucite or in bakelite. When the latter is used, it is advisable to make the mount at a somewhat higher than normal temperature and pressure, say 350° F. and 5000 psi. These conditions will increase the resistance of the bakelite to the alkalis in the etchant.

Use of the Etchant

Microstructural features revealed by the etchant and some instances of its usefulness in metallography are illustrated in Fig. 1 to 6.

Figure 1 shows severe scaling on the flash of a flash weld in a medium-carbon steel plate. (The section was annealed after welding to bring out the banded structure of the plate.) At left is its appearance after etching with nital. This photomicrograph shows three regions — unaffected banded steel, a zone of decarburization, and a mass of scale (solid dark region). At center is the same area, repolished and etched with the permanganate-dichromate etchant. The unaffected steel, the decarburized zone, and the scale are again visible. In addition, however, the reagent reveals a fourth zone, a narrow band in the metal at the scale-metal interface. This zone follows closely the contour of the interface and occupies the outer part of the decarburized region defined by the nital etch. The narrow band is white (unstained) and stands out in contrast to the gray scale, the medium blue decarburized zone, and the dark blue unaffected steel. At right, in Fig. 1, is another view of the white band at a higher magnification.

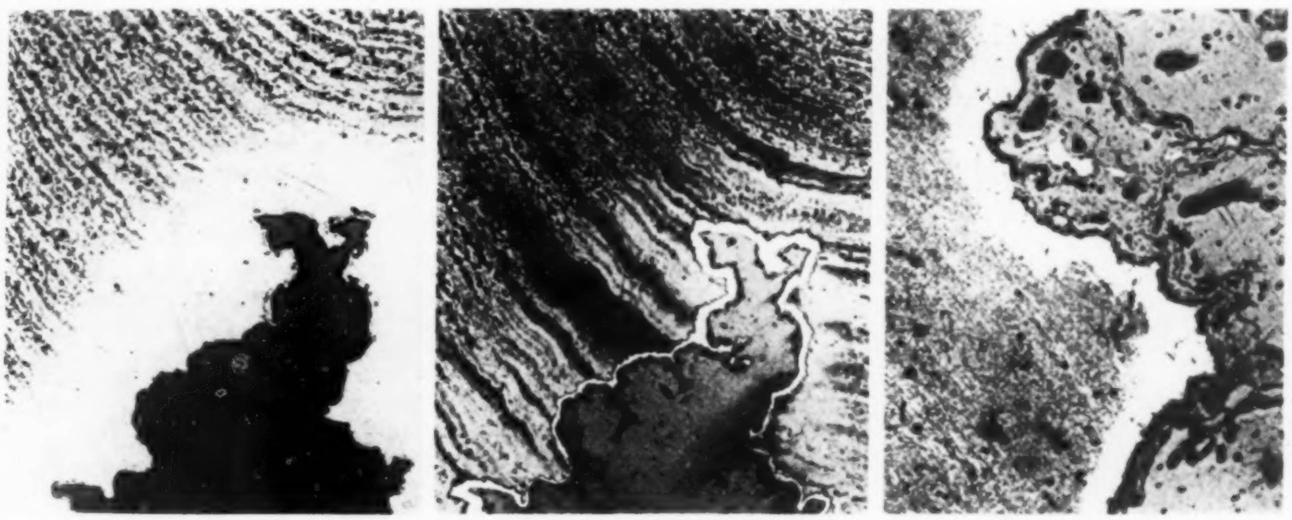


Fig. 1 — Scaled Flash of Flash Weld in Medium Carbon Steel, Annealed After Welding. Left — etched with nital: 100×. Center — same area etched with Hall's reagent. Right — portion of center at 500×

From its form, its position in the metal adjacent to the scale, and its negative response to the etchant, the narrow white band is certainly different from the decarburized zone, from which it is not distinguished by the nital etch. From its location and the oxidizing conditions under which it formed, it seems appropriate to assume that this band is enriched in oxygen (is "oxidized"), and hence this evidence points to the ability of the reagent to indicate oxygen-rich areas in steel. Being substantially metallic, however, the thin white band is less oxidized than the scale.

Scaling of steel is a complex process involving the inward diffusion of oxygen and the outward diffusion of iron (and often its alloying elements), with the formation of a series of oxides and oxidation products increasing in degree of oxidation from inside to outside. In conjunction with this process, carbon is lost from the steel by outward diffusion and oxidation. (Two good publications dealing with these phenomena are "The Oxidation of Iron and Steel at High Temperatures", by L. B. Pfeil, *Journal* of the Iron and Steel Institute, V. 119, 1929, p. 501, and "The Loss of Carbon From Iron and Steel When Heated in Decarburizing Gases", by A. Bramley and K. F. Allen, *Engineering*, V. 133, 1932, p. 92, 123, 229 and 305.) The extent of carbon loss is marked by the zone of decarburization, which is readily revealed by the

ordinary etchants (Fig. 1, left). In addition, another zone, the narrow white band shown in Fig. 1, center and right, is produced. This band is probably the region where the oxygen concentration in the decarburized iron is rising to the level where visible oxide forms; it may be the oxygen-iron solid solution, variously reported★ to contain from negligible amounts up to about 0.05% oxygen by weight at room temperature. In addition, the zone may contain many submicroscopic oxide particles. It may be considered, then, to be a region intermediate in degree of oxidation between the condition of decarburization and that of visible scale.

Figure 2 shows at left, in transverse section, the edge of a Mo-W-Cr-V high speed steel bar heated in air 8 hr. at 2000° F. and water quenched. The etchant is nital. Unaffected steel, a decarburized zone, and scale (the dark gray layer at the top) are observable, much as in the flash weld of Fig. 1. At right is shown the same material repolished and etched with the new oxidizing reagent, and again a narrow white zone is revealed in the steel at the scale-metal interface, representing a condition of oxidation intermediate between decarburization and visible scale.

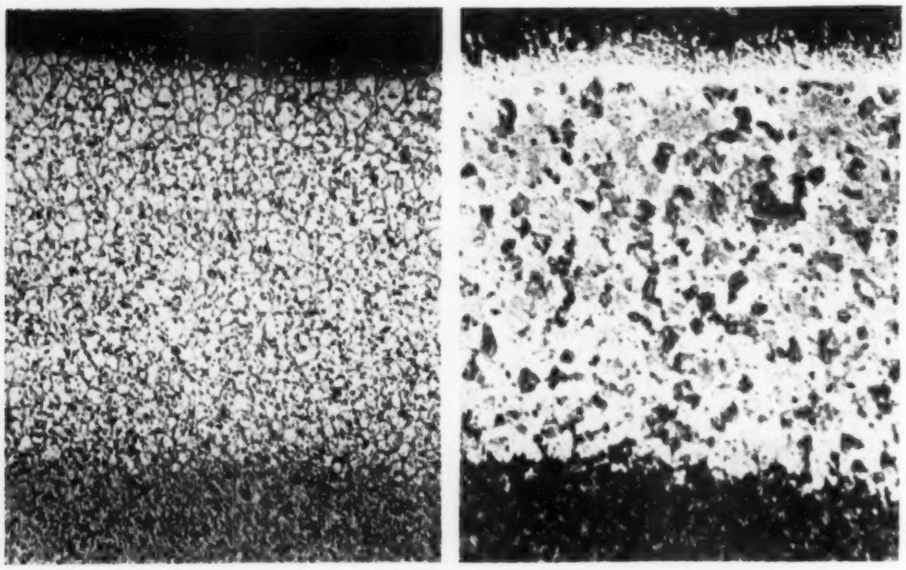
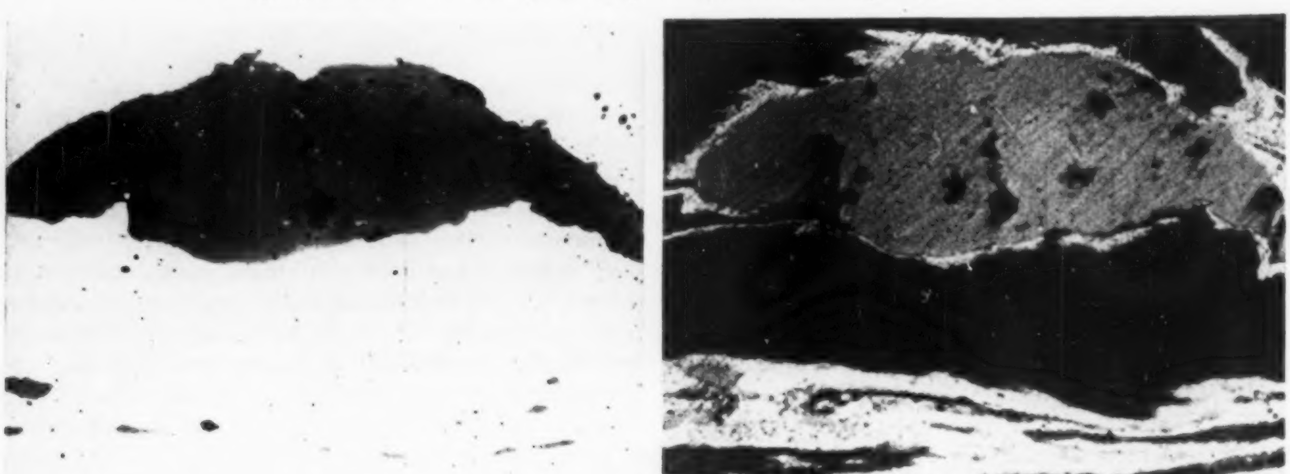


Fig. 2 — Decarburized High Speed Toolsteel. 100×. At left after nital etch, at right after Hall's etch

Figure 3 illustrates the results of one of several experiments conducted to demonstrate the relationship between the etchant's effect and the condition of

★See "Iron and Oxygen", by F. S. Tritton and D. Hanson, *Journal* of the Iron and Steel Institute, V. 110, No. 2, 1924, p. 90; "Solubility of Oxygen in Solid Iron", by N. A. Ziegler, *Transactions* of the American Society for Steel Treating, V. 20, 1932, p. 73; "Physikalische Chemie der Eisenhüttenprozesse", by H. Schenck, published by Julius Springer, Berlin, 1932, p. 131.

Fig. 3 — Artificial Oxide Inclusions (500×) in Low Carbon Steel Rod After Forging at 1900° F. At left is sample as polished, at right after Hall's etch



oxidation of the steel. Iron oxide inclusions were intentionally added to a ¾-in. diameter cold drawn low carbon steel rod by drilling a hole into one end, $\frac{3}{16}$ in. diameter, 2 in. long. The hole was packed with dry ferric oxide powder and plugged with a low carbon steel rod. The piece was heated 20 min. at 1900° F., and hot forged from ¾ in. round to ½ in. square. Figure 3 shows a group of the resulting oxide inclusions after polishing a section. The black areas in the large inclusion are voids. The same area etched with the alkaline permanganate-dichromate reagent is shown at the right of Fig. 3. The large inclusion is surrounded by an irregular white zone. The smaller inclusions and pepper-and-salt oxides appear within white bands. The elongated character of the structure is the result of forging.

The results shown in Fig. 3 do not mean that all oxide inclusions in iron alloys will be surrounded by oxidized zones or while halos, or contained within white bands. To produce such white areas with the reagent, conditions must have been such as to build up an appreciable oxygen concentration in the adjacent metal.

Figure 4 is a photomicrograph, in transverse section, of the edge of a mild steel rod heated in air 24 hr. at 2000° F. and water quenched. The oxidizing etchant clearly reveals the intergranular nature of the diffusion of oxygen into the metal. In addition, within the grains themselves, particles of oxide may be seen, surrounded by white halos, high in oxygen, produced by diffusion. Scale is not observable because it spalled off during quenching.

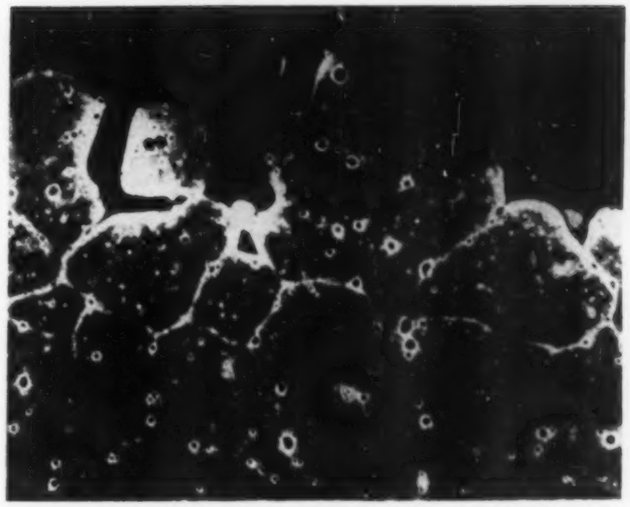


Fig. 4 — Edge of Mild Steel Rod After Heating 24 Hr. in Air at 2000° F. Etched with Hall's reagent; 250×

Since many of the illustrations involved heating in air, a question may arise as to the influence of nitrogen upon the etching effect produced by the new reagent. To answer this, specimens of S.A.E. 1020 steel plate were heated ½ hr. at 1700° F. in air, and others in purified nitrogen. The specimens heated in air scaled and showed a white zone in the metal at the scale-metal interface after etching. The specimens heated in nitrogen did not scale and showed no white zone after etching.

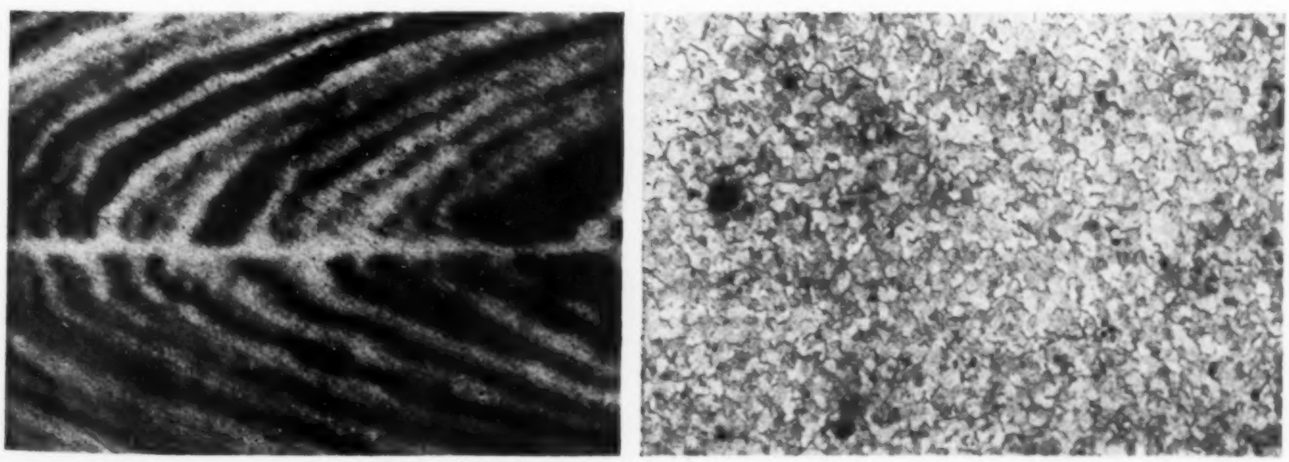


Fig. 5 — Weld Line of Flash Weld in Medium Carbon Steel Plate, As-Welded (Not Heat Treated). 100×. Left — Hall's reagent; right — Oberhoffer's reagent

Application of the etchant to flash welds is illustrated in Fig. 5, which shows part of the weld line in a medium carbon steel plate as-welded. The banded structure of the plate is seen to be distorted (outbent) by upsetting during welding.

In this instance, the etching effect at the weld line is not intense, suggesting relatively low oxygen concentration. The same weld-line region, repolished and etched with Oberhoffer's reagent, is shown at the right of Fig. 5. Neither the weld line nor the banding of the steel is revealed; these structures were not developed by Oberhoffer's etch unless the flash weld was annealed or normalized.

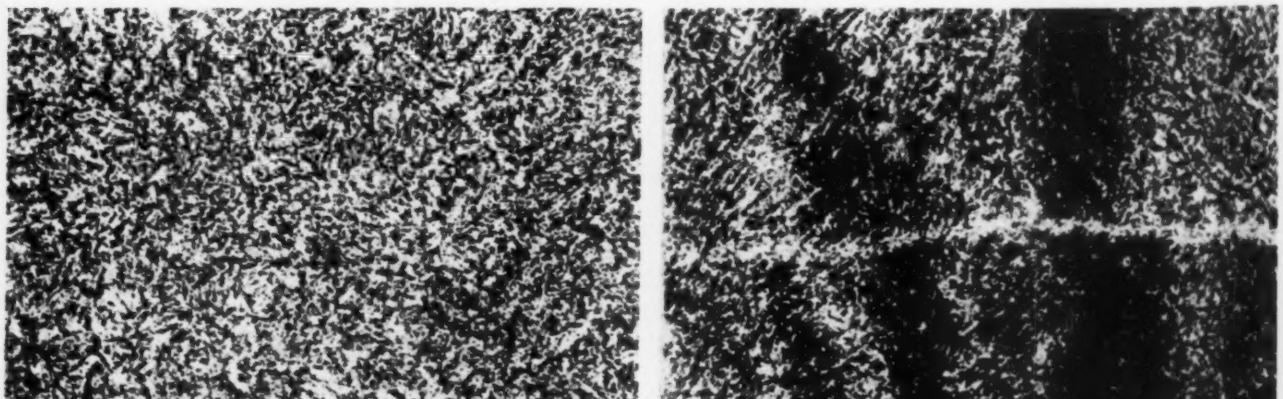
The new reagent has also been successful in distinguishing layers of metal high in oxygen along the weld lines of pressure gas welds (solid-phase welds) in A4135 tubing $3\frac{1}{16}$ in. o.d. x $\frac{13}{32}$ in. wall. As pointed out in the articles by Mr. Fine and his associates (*Metal Progress* for January, February and March) it is difficult to follow the weld line, even though marked by islands of oxide, when etched with nital. As etched with the alkaline permanganate-dichromate reagent, however, it is readily revealed as a distinct white band. It is inferred that this band is enriched in oxygen.

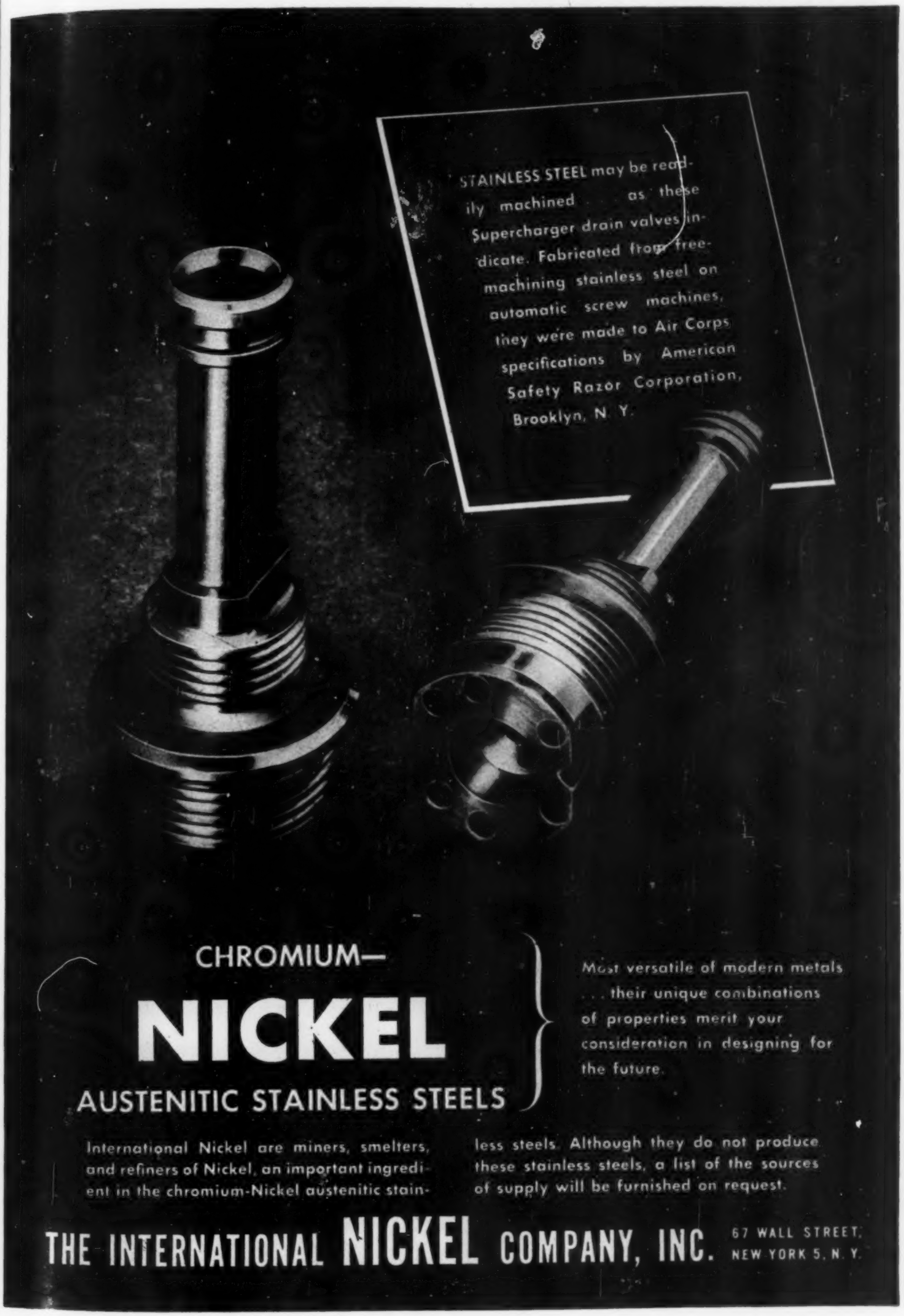
Nital often gives a false impression of structural homogeneity in the weld-line region after certain postweld heat treatments. This is illustrated in Fig. 6, which shows the effect of oil quenching from 1575° F. after 45 min. at temperature and drawing at 825° F. The structure appears homogeneous as etched with nital. However, mechanical tests on specimens similarly treated still indicated weld-line brittleness, and the new etchant demonstrated that the heat treatment did not produce homogeneity. This is evident in the view at the right of Fig. 6, which shows the same area as before, but repolished and etched with the permanganate-dichromate reagent. The heat treatment redistributed the carbides in the steel, but evidently did not induce appreciable diffusion of oxygen away from the weld-line region.

Applications of the Etchant

Although the etchant was originally developed for investigating the metallurgy of pressure gas welds and flash welds, the illustrations given here indicate that it has a variety of other possible applications. It may be useful in studying other types of welds, as well as in studying the effect of oxygen, air, and other oxidizing media upon the microstructure of iron and iron alloys in such operations as melting, refining, carburizing, hardening, annealing, and normalizing. Finally, the new alkaline reagent appears useful over a wide range of ferrous compositions from plain carbon steels to aluminum-silicon-chromium-iron alloys, high in chromium.

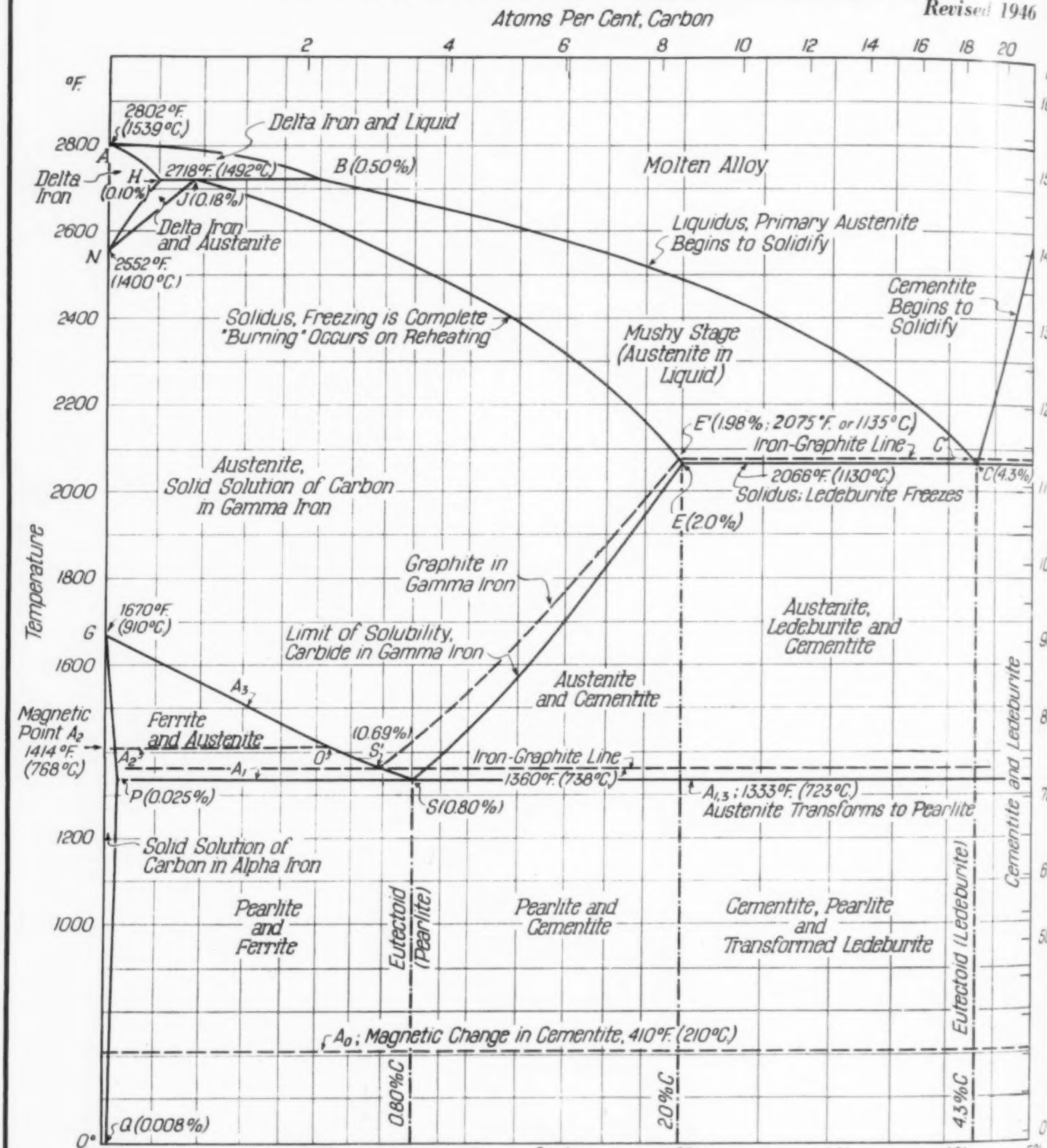
Fig. 6 — Pressure Weld in A4135 Tube, Quenched From 1575° F. and Drawn at 825. 500×. Nital etch at left shows homogeneous structure; Hall's etch at right shows oxygenated metal at weld line and banded structure in base metal




STAINLESS STEEL may be readily machined as these Supercharger drain valves indicate. Fabricated from free-machining stainless steel on automatic screw machines, they were made to Air Corps specifications by American Safety Razor Corporation, Brooklyn, N. Y.
CHROMIUM—
NICKEL
AUSTENITIC STAINLESS STEELS
Most versatile of modern metals . . . their unique combinations of properties merit your consideration in designing for the future.
International Nickel are miners, smelters, and refiners of Nickel, an important ingredient in the chromium-Nickel austenitic stainless steels. Although they do not produce these stainless steels, a list of the sources of supply will be furnished on request.
THE INTERNATIONAL NICKEL COMPANY, INC.
67 WALL STREET, NEW YORK 5, N. Y.

Iron-Carbon Equilibrium Diagram

Revised 1946



Principal points and lines, especially *G-S-E-J*, adjusted from positions in former edition of *Metal Progress* data sheet, to agree with diagram prepared for the subcommittee on phase diagrams, Kent R. Van Horn, chairman, John S. Marsh and F. N. Rhines, for inclusion in the 1947 Metals Handbook. Point *Q* according to J. H. Whiteley, *Journal* of the Iron and Steel Institute, 1936.

Superalloys

for High Temperature Service in Gas Turbines and Jet Engines

By F. S. Badger
H. C. Cross
C. T. Evans, Jr.
Russell Franks
R. B. Johnson
N. L. Mochel
Gunther Mohling

VERBATIM report of a round-table discussion at American Society for Metals' National Metal Congress and Exposition held in Cleveland, February 5, 1946:

CHARLES T. EVANS, JR. *(Chairman)* — I wish to introduce my fellow members on this panel for superalloys in jet engines and gas turbines. At my right is Norman L. Mochel, manager of metallurgical engineering for Westinghouse Electric Co. in its South Philadelphia plant; the next gentleman on my right is Gunther Mohling, associate director of research at Allegheny Ludlum Steel Corp.'s Watervliet (N. Y.) plant; last is F. S. Badger, who is director of research for Haynes Stellite Co. in Kokomo, Ind. The first gentleman on my left is Russell Franks, chief metallurgist of Union Carbide and Carbon Research Laboratories in Niagara Falls, N. Y.; the gentleman on his left, R. B. Johnson, is metallurgical engineer in the Thomson Laboratories of General Electric Co. at West Lynn, Mass. (Mr. Johnson is substituting for W. L. Badger who is not able to be here because of illness.) Finally the gentleman on the left end of the table is Howard C. Cross, formerly supervisor in charge of research on high temperature materials done by the National Defense Research Committee (N.D.R.C.), and who is now supervisor in the metallurgical division of Battelle Memorial Institute at Columbus, Ohio.

All these gentlemen have been working intensively for the last five years, at least, in the field of special alloys for aircraft engine superchargers, jet engines and power gas turbines. Mr. Mochel, Mr. Franks and myself are members of a subcommittee of National Advisory Committee for Aeronautics (N.A.C.A.) which has studied over 100 new compositions in the last four years. I would like to emphasize that this public discussion must be under wraps, so to speak, to the extent that we must frequently speak in generalities. Many specific references and actual compositions and properties of useful alloys are still classified as restricted information [and still are! — EDITOR.]

I wish to have the panel discussion as brief as possible because we would like very much to have an interesting open discussion from the floor.

I would like first of all to ask Mr. Mochel to give us a brief discussion of the high temperature problems involved in materials used in high speed rotating equipment prior to the advent of these new prime movers, which are now using hot gases other than steam.

MOCHEL — The topic we are going to discuss tonight is materials for jet engines. Of course jet engines, as we will talk about them, will include gas turbines for other purposes than aircraft propulsion, and we immediately think about high temperature, high speed, highly stressed rotating parts, and the casings that must house this equipment. For commercial prime movers we will also naturally think of reliability of performance; the matter of life is going to be an important variable in our problem. Some of the equipment we talk about is going to have a rather short life, and some is expected to have a rather long life.

I think that a look backward into the field of steam turbines — in which we have also dealt with high speed, highly stressed rotating parts and housing casings which had a rather long life expectancy — would be of interest. For about 20 years before 1940 American engineers had been engaged in rather intensive research in this field. We had made marked progress. The operating temperatures in the services which supply our

power and our light have been creeping steadily upward. At the beginning of the war quite a number of turbines were in operation at temperatures between 925 and 975° F. At least one turbine had been built to operate steadily at 1000° F. We also know from experience that some turbines have by accident operated at higher temperatures. That then was the temperature level at which we were working directly before the [illegible] — a top limit of about 10[illegible] F. and a very long expected life because steam turbines are designed to last at least 20 years.

Now, during this developmental period we had come to recognize some very definite fundamental relationships in designing machines for operation at high temperatures. Figure 1 summarizes these relationships. It is a small simple square. You will find "Stress" at the bottom; you will find "Temperature" at the top; at the left you will find "Strain" meaning allowable deformation; and at the right you will find "Time" meaning expected service life. This represents the fact that in the use of metals at high temperatures where stresses are involved one cannot talk usefully about any one of these figures; you must talk about stress *at* a temperature *with* an expected life and *with* an allowable deformation. As we approach the requirements of the gas turbine, we will see more than ever the importance of keeping always in mind this fundamental aspect which came from our steam turbine practice.

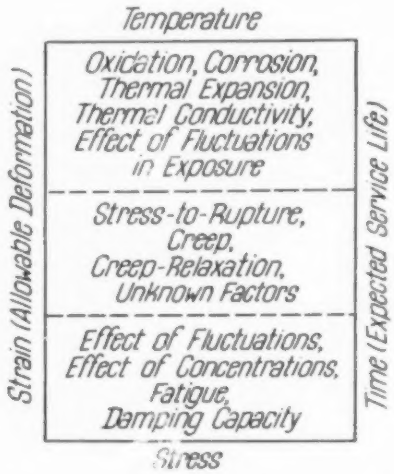


Fig. 1 — Metallurgical Considerations (Inside Square) to Satisfy the Designer's Demands (Outside of Square)

EVANS — Thank you Mr. Mochel. We would like now to describe very briefly the operating characteristics of a power turbine and give you some idea of the high temperature problems in the new field which has come up so recently — that is, the field of superchargers, jet engines and the power gas turbine. You will notice on the tables and the platform some parts which we have collected for exhibit, thinking that they would add to the value of this discussion. As we progress, the various panel members will describe what these units are. But first I would like to ask Mr. Johnson to give us some idea of the operating characteristics and the high temperature materials used in the aircraft supercharger.

JOHNSON — In aircraft turbo superchargers the chief metallurgical problem was the turbo wheel and the buckets; the sheet metal parts did not cause near so much difficulty. The temperature surrounding the wheel runs to about 1200° F. as a maximum at the rim and about 500 to 600° F. at the center. Besides being able to withstand the high stresses of a wheel spinning at 25,000 r.p.m. at these relatively high temperatures, the problems of forgeability, machinability and weldability had to be considered. The availability of the alloying elements also was a very important consideration, as large tonnages of metal were involved. Thousands of these small power units had to be made.

The earlier methods of evaluating materials for turbine wheels were chiefly the short-time physical tests at elevated temperatures. This method of testing was found to be decidedly improper for selecting suitable materials for this new service. Another method of testing was adopted which came to be known as the stress-rupture test. This method of testing places a standard test bar in a furnace at a known temperature and under a constant stress, the time for failure under these conditions being recorded.*

This method of sorting the bad from the good materials was used in the selection of metals for the turbo bucket also. However, both the wheel and bucket required that we take the other common physical properties into consideration.

The problem of material selection in the jet engine was much the same as in the turbo supercharger, but to get a clearer concept of the parts which will be discussed tonight, it would be well to look at a cross section of a jet engine.

Figure 2 shows a British design (the Whittle W2B engine) which is schematically similar to the I-16 manufactured by General Electric for the American P-59 airplane. The flow of air is from the compressor *C* to the outer combustion chamber *CC*, through the combustion chamber liner *CL* (which will be the first portion of the machine that will be taken up in tonight's discussion of high temperature materials). In the combustion chamber, the compressed air is mixed with atom-

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*EDITOR'S NOTE — A comprehensive, although brief, discussion of the stress-rupture test and other methods of evaluating metals under load at elevated temperature is contained in an article by the round table's chairman, C. T. Evans, Jr., entitled "Wrought Heat Resisting Alloys for Gas Turbine Service" in *Metal Progress* for November 1945.

ized fuel *F* and ignited. Once ignited by spark plugs, the burning is continuous. The fuel and air burn to raise the temperature of the gas to a very high value. The design of the combustion liner is of prime importance in order that even heating takes place; if it is not carefully engineered, the liner will warp into the path of the extremely hot gases and be destroyed.

From the liner the gas flows through the nozzle diaphragm *N* (the second item that will be discussed), then through the buckets *B* on the turbine wheel *W* and finally is exhausted through the tail cone *T* to the atmosphere.

Later models of General Electric jet engines have direct rather than the reverse flow of gases shown in Fig. 2 of the Whittle engine.

Mochel — Figure 3 [page 100] is of the Westinghouse "Yankee" 19-B jet engine. You will notice here that the air enters at the inlet end and passes directly through the unit and out the exhaust end or the jet nozzle at the rear end. The axial flow compressor is driven by the same shaft as the turbine [Fig. 4, page 101]. Lubricating oil is cooled by the inrush of cold air at the front; this inlet air is compressed by the series of compressor blades and travels on to the combustion chambers. Hot gas then drives the turbine blades and escapes out the exhaust nozzle at the other end.

When we talk about the liner for the combustion cone or combustion cell, we mean the conical member marked "burner ring" in Fig. 3. That is formed of thin sheet metal perforated to admit turbulent air for high velocity combustion. Hot gases of combustion strike the diaphragm blade or stationary vanes and then the moving blades, carried in the turbine wheel disk, and then the jet exhausts. The high temperature members* are, of course, the conical burner ring or basket of the combustion element, the stationary vanes, the moving turbine blades, the turbine disk, and the sheet metal which forms the exhaust nozzle.

*Editor's Note — A publicity release by Westinghouse Electric Corp. notes that the gases entering the turbine nozzle vanes of the 19-B jet engine are at 1200° F. and the maximum allowable temperature is 1500° F.

Evans — The more complex picture shown in Fig. 5 [page 102] is the first successful prime mover of power gas turbines constructed in this country. It is a 2500-hp. unit made by the Elliott Co. and it has a relatively complex cycle. The air, just ordinary atmospheric air, comes in at the top right. It then goes through what is known as the low pressure compressor and on around through a duct to what we call an intercooler. (All this does is reduce the temperature of the compressed air so that we will not have such a large volume for the next stage to handle.) From the intercooler the air goes immediately to the high pressure compressor and immediately up through another heat exchanger, which we call a regenerator, where it picks up as much heat as it can from the exhaust gas.

This hot compressed air, at a temperature of about 750° F. max., then goes on into the combustion chamber shown at the very top of the diagram, where it mixes with the fuel and goes

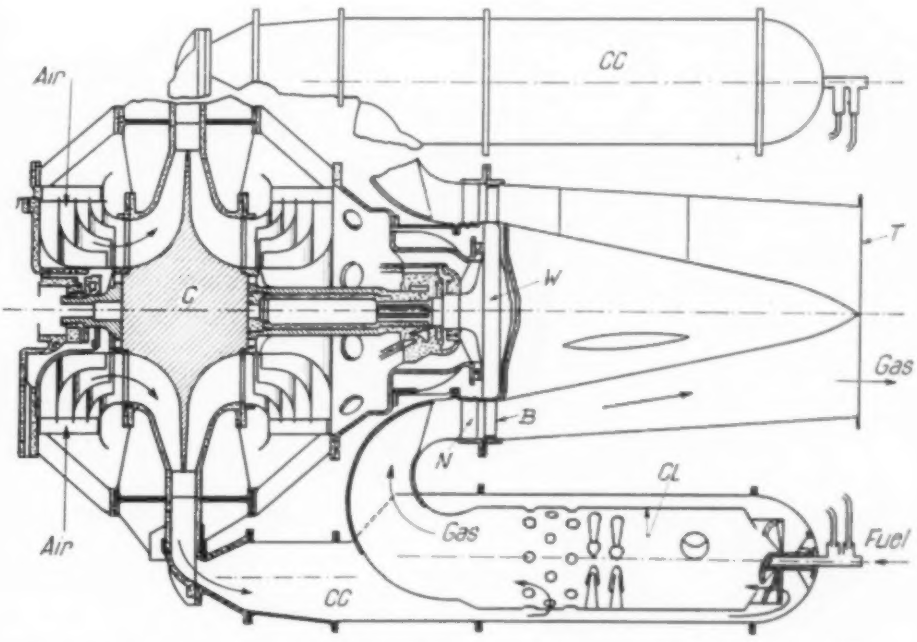


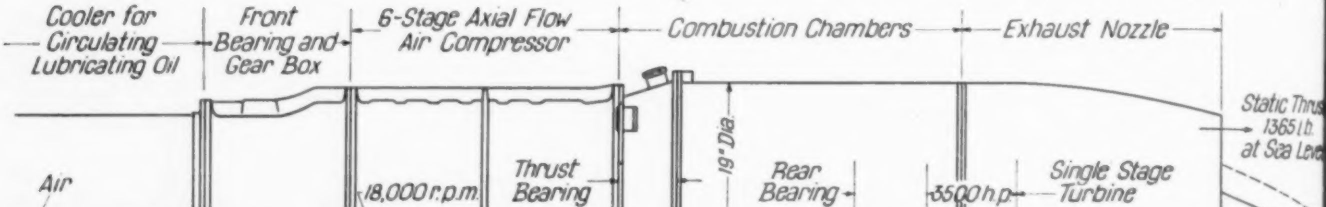
Fig. 2 — Assembly of W2B British Engine, the Parent Design of the Rolls-Royce "Welland" Engines That Powered the "Meteor" Fighter, and the G.E. Engine for the Bell P-59. (From "The Early History of the Whittle Jet Propulsion Gas Turbine", James Clayton lecture by Commodore Frank Whittle before the British Institution of Mechanical Engineers, Oct. 5, 1945)

through what is known as the high pressure turbine (top left). This is a gas turbine. The exhaust from this high pressure gas turbine goes on to the low pressure gas turbine, being heated somewhat in the low pressure combustion chamber, en route. Exhaust from the low pressure turbine in turn goes out through the regenerator to exhaust.

The net horsepower of this unit is delivered on the propeller shaft at lower left of the diagram (Fig. 5) taken off the end of the low pressure turbine. The high pressure turbine at the top does not deliver any *net* horsepower at all; its only function is to drive the low pressure compressor. The low pressure turbine actually has a rating of 5000 hp., but it only delivers 2500 hp. net due to the fact that 2500 hp. is needed for driving the high pressure compressor.

The temperatures in this power unit are noted alongside the various parts in the diagram. Temperatures are severe in the two turbines, in the duct work between them, and in the combustion chambers. At any rate, the parts on the left-hand side of the diagram must all be made of extra high temperature metals we call superalloys.

Fig. 3 — Half Longitudinal Cross Section, Half Side Elevation of Westinghouse 19-B Axial Flow Gas Turbine. Maximum static thrust at sea level with 1500° F. turbine inlet temperature is 1365 lb. Installed weight, 847 lb.



It might be worth mentioning that the forerunner of this Elliott turbine, as far as high temperature machinery is concerned, was also a turbo supercharger which was not used for aircraft but for supercharging 4-cycle diesel engines generating over 250 hp.

To briefly mention the increase in operating temperatures, the earlier supercharger operated at 1020° F. and a maximum stress of 28,000 psi. The propulsion unit shown in Fig. 5 operates at 1200° F. (temperature in the high pressure turbine) with a maximum stress 8000 psi.

Mochel — Before turning our attention to other things we might mention one other matter in connection with this same type of unit. Just ahead of each of the turbines are combustion chambers from which burned fuel goes on into the turbine. This is what one would call an "open cycle", one in which the products of combustion are merged with the compressed air and the resulting mixed gas goes into the turbine. There is a development in Switzerland in which the products of combustion are not added to the air stream but are kept separate from it. In other words, the Swiss would insert an air heater in place of each of the combustion chambers, heat the compressed air in a closed system and do not merge the products of combustion with it at all. The exhaust from the low pressure turbine is joined to the inlet of the low pressure compressor, and the air goes around and around in a closed circuit. Naturally, you will appreciate that corrosion problems may arise from the nature of the fuel, and that the closed type of system would always operate on clean air — or even on an inert gas — and not have the products of combustion, possibly sulphur and other things, added to it. (I thought I had better mention this in passing.)

Gas turbines may, of course, be used for other purposes and may be much simpler in shape than the elaborate machine just described. Any place where present motive power is not doing a good job is a place for the gas turbine to become real competition. Numerous gas turbines are used in petroleum refineries where excess gas is available. I have in mind a 2000-hp. axial flow compressor unit driven by a gas turbine. The air compressor has simply an ordinary carbon steel rotor (no high temperature is involved at all) carrying the blades, and stationary blades or vanes are in the casing — this is purely for compressing the air. The compressed air at moderate temperature passes to the burners for the gas turbine, which is simply a multistage turbine wherein hot prod-

ucts of combustion (gas) take the place of superheated steam (also a gas, by the way). Hot gas comes from the combusting element rather than a steam boiler, passes through the turbine and goes out through the exhaust. The available power, for an electric generator or other purpose, is the surplus produced by the turbine over that required to compress the air for its own operation.

The hot members in such a simplified turbine would be the rotating rotor (the body that carries the rotating blade), the blades attached to the rotor, the stationary blades, and the casing. Certain portions of the combustion chamber might become quite hot, even though the turbine temperatures might be moderate.

By means of this introduction, we have tried to picture for you just what we are talking about in the way of materials — to give you an idea of a new type of power unit which includes jet engines, gas turbines for aircraft, gas turbines for ships, for locomotives and for possibly a variety of industrial applications. Material problems are pretty much the same in all of these.*

CHAIRMAN EVANS — Right now it would be in order for me to direct this discussion to the metallurgical aspects of turbines, since this is a metallurgical meeting. We would like first to discuss some of the metallurgical problems in the less complicated parts of the machinery. I will now ask Mr. Johnson to tell us briefly about some of the metallurgical problems in the combustion chamber and the duct work.

JOHNSON — The problem in combustion chambers is not only one of material but is an engineering design problem as well. To reduce warpage the flow of hot gas must be such that the combustion chamber is evenly heated. Warpage of the chamber into the hot gas path will destroy almost any material very rapidly. These chamber walls can normally be expected to withstand 1500° F.; thin sheets with welded joints were indicated from a weight-saving standpoint. Longitudinal butt joints were designed for a flush joint

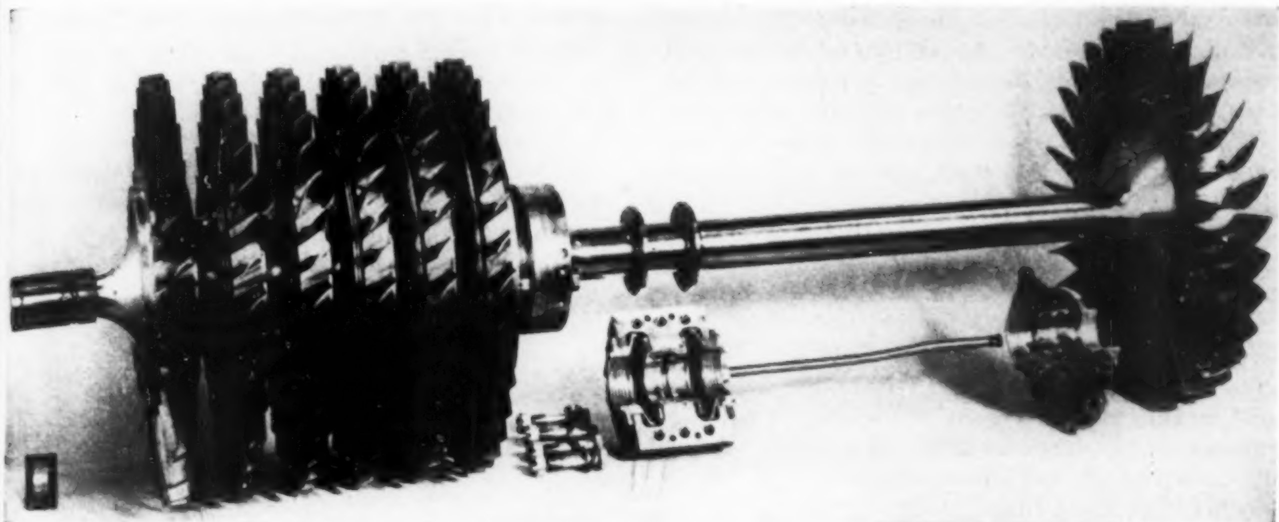


Fig. 4 — Rotor Assembly and Bearing Segments of 19-B Turbine. Turbine shaft and disk is 19% nickel, 9% chromium stainless plus tungsten and molybdenum; turbine buckets at right end are Westinghouse K-42-B alloy; compressor spindle (and its disks) is a single aluminum alloy forging; blades are castings keyed in place

*EDITOR'S NOTE — On the basis of eight years' experience with a number of gas turbine driven air compressor units installed in petroleum refineries where the Houdry process is used for high octane gasoline, Allis-Chalmers Mfg. Co. designed a 3500-hp. gas turbine for experimental study by the U. S. Navy's Engineering Experiment Station at Annapolis. This unit was given a public showing in March, after it had made many experimental 50-hr. runs with maximum turbine temperatures of 1350° F. The design contemplates maximum turbine temperature of 1500° F., at which the main operations are as follows: Air from a 20-stage axial flow compressor and at 365° F. enters a counter-flow regenerator, picking up heat to 750° F. This hot air is used to burn atomized fuel oil, and the hot gas enters a five-stage turbine at 1500° F., and leaves at 1025° F., going to the regenerator from which it exhausts at 640° F. Blades and turbine disks are made of Timken 16-25-6 alloy, the two disks and diaphragms handling the hottest gas being cooled by jets of cold air playing on down-stream faces. Other high temperature parts and piping are of 25-12 Cr-Ni alloy. Pipe is backed up with mineral insulation which in turn is surrounded with a jacket which is cool and which carries the stresses.

without the necessity of grinding. These were made by clamping the joint in a fixture, backing it with hydrogen, and then welding it by the atomic-hydrogen process. The hydrogen backing was provided by burning hydrogen in a groove milled in the backing bar of the fixture. On thicknesses up to $\frac{1}{16}$ in. the edges were butted up square; using the fixture as mentioned, the seam was welded without the addition of filler or the use of flux. This resulted in a nearly flush joint that did not require cleaning and had excellent physical strength. The use of filler was eliminated by clamping both sides of the joint tightly within ¼ in. of the joint. Bringing the heat of the arc to the metal expanded it and forced it to hump at the joints. This hump was melted down, giving a flush weld. As the metal cooled and contracted a little elongation occurred between the tight clamps, but this was so slight that it had no harmful effect upon the joint. Some of these combustion tubes and their assembly fixture are shown in Fig. 6 (page 103).

To resist the uneven heating that might occur, the high temperature strength of the material selected has a great deal to do with whether the unit is going to operate for a great length of time. The material we have used in the General Electric I-16 and I-40 machines has been the alloy Inconel (80% nickel, 14% chromium, 6% iron). I do not know what Mr. Mochel has been using in the Westinghouse machines. Perhaps he will tell us.

Mochel — We started out using ordinary "18-8 moly". We changed to Inconel and had some success with that, but we believe that the 25% chromium, 20% nickel austenitic alloy with 2% silicon is probably a better all-around material for the combustion units. That is the standard material for the angular "basket" we use today.

Evans — I wonder if we don't have something available a little bit better than 25-20, possibly for severe wear.

Mochel — We are not confronted with such a necessity at the moment but we expect to be.

Badger — I believe that the best service from tests has been obtained from the alloy known as Vitallium, which, as perhaps many in the audience know, is a dental alloy which has been modified to increase its ductility and its rolling properties. We produce it under the name of Haynes Stellite alloy No. 21. General Electric's I-16 units have been tested with this material for a combustion chamber liner and have shown, I understand, from three to ten times the life of the formerly used material, due chiefly to its high strength at elevated temperatures. However, it is quite a wide step from Inconel (and 25-20 with silicon) to an alloy based on cobalt. Some intermediate alloys both in properties and in price are being tested at the present time, although no results have yet been obtained. One of these is Hastelloy alloy C.

Evans — Could you give us a general idea of the composition of Vitallium?

Badger — Vitallium is a cobalt-base alloy carrying about 27% chromium, 6% molybdenum, 0.20 to 0.30% carbon, a small percentage of iron as an impurity, and 2% nickel.

Evans — Hastelloy C that you mention — is it a similar alloy?

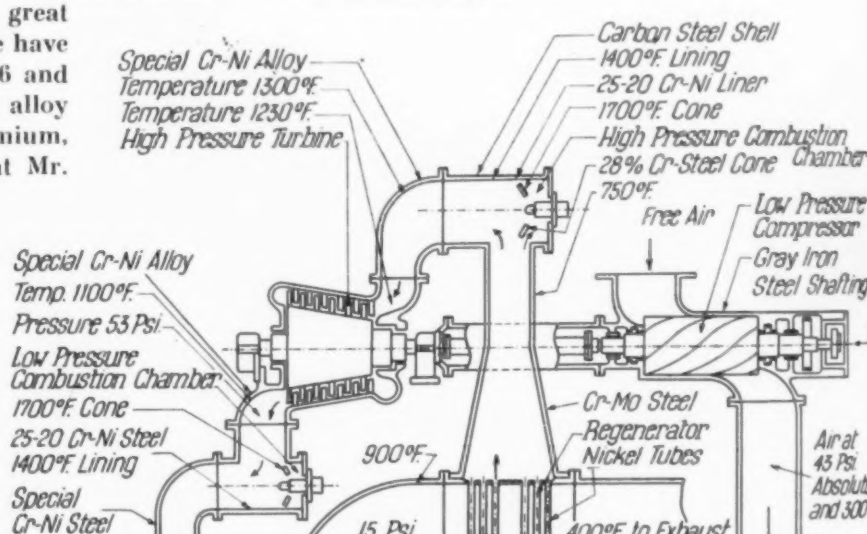


Fig. 5 — Diagram of Elliott Gas Turbine Cycle for Ship Propulsion and Temperatures and Materials of Construction of Important Parts

Badger — Hastelloy alloy C has a nickel base with 15% chromium, 17% molybdenum, 5% iron, carbon under 0.10%, and 2% tungsten.

Evans — I think that covers the combustion chamber problem fairly well. We didn't talk about the ducts, however — that is, the tail cone and miscellaneous high temperature parts that go into the exhaust system. Mr. Johnson, could you explain briefly what you are using there?

Johnson — Well, 18-8 columbium is what we have adopted chiefly. However, in comment on what Mr. Badger just said, I think he would have a difficult time to make Vitallium sheet in any quantity in a rolled condition if it were to be adopted for a liner. What would you want to say about that, Mr. Badger?

Badger — It is hard to handle in rolling, particularly in bar stock form. Actually in sheet form we do not have too much difficulty. It just takes from three to five times as long to roll as the Inconel you are now using.

Mochel — Before we leave the combustion cell item, I should call your attention to my belief that there is a great problem for the *designer* to solve in the combustion liner. I question very much whether a metallurgist is going to solve it. I believe that by the utilization of proper air — of which there is always an abundance — we may get rid of excessive surface temperatures; when that day comes we may be able to get by with some of the less expensive materials. Of course, it may be even then that the very expensive materials may fit in and give increased life and lower maintenance.*

As to the duct for the exhaust cones, we have used columbium-bearing 18-8, although at the present time we make our exhaust nozzles of the 25-20, 2% silicon material, the same as is used in the combustion liner.

Johnson — I would like to ask, Mr. Mochel, whether you have had any experience with the chromium-aluminum combinations.

Mochel — Chromium-aluminum?

Johnson — Yes. Something on the order of 20% chromium and 7% aluminum.

Mochel — We have not used that. Invariably the matter of fabrication is an important item. One likes to have sheet metal that he can readily

*Editor's Note — In the Ninth Wright Brothers Lecture presented before the Institute of Aeronautical Sciences by H. Roxbee Cox on the subject of "British Aircraft Gas Turbines", the speaker said that the sheet metal construction for the bulk of the combustion systems on all engines was a prolific source of trouble. Failures at welded joints were gradually overcome by study of resistance welding techniques, correct choice of material, and careful attention to finish. Fatigue failures have been eliminated by careful design of contour, stiffening, and reduction of sources of vibration. Fretting failures (seizure) have been avoided by arranging small air gaps at susceptible junctions. Failures from flame impingement and poor heat distribution in the flame tubes have disappeared with designs having no thin metal parts in the flame region, and with improved fuel injection. Failures in blades, once common, are avoided by accurate manufacturing, by avoiding small radii at root junctions, by providing for turbine vibration, and by improving the material. Standard turbine blading is "Nimonic 80", developed by Mond Nickel Co. in 1940; "it has excellent creep and fatigue properties at the working temperature, is sufficiently easily forged at about 2000° F. to permit blanks to be stamped practically to finished size". Steep temperature gradients in gas turbine disks have caused much special research.

In commenting on this paper, Carlton Kemper, executive engineer of aircraft engine research laboratory, National Advisory Committee for Aeronautics, said: "Improving the metallurgical properties of materials for combustion chamber liners, turbine disks and blading will increase not only the efficiency of the unit, since it will permit operating at higher temperatures and higher compression ratios, but also the life of the jet engine."

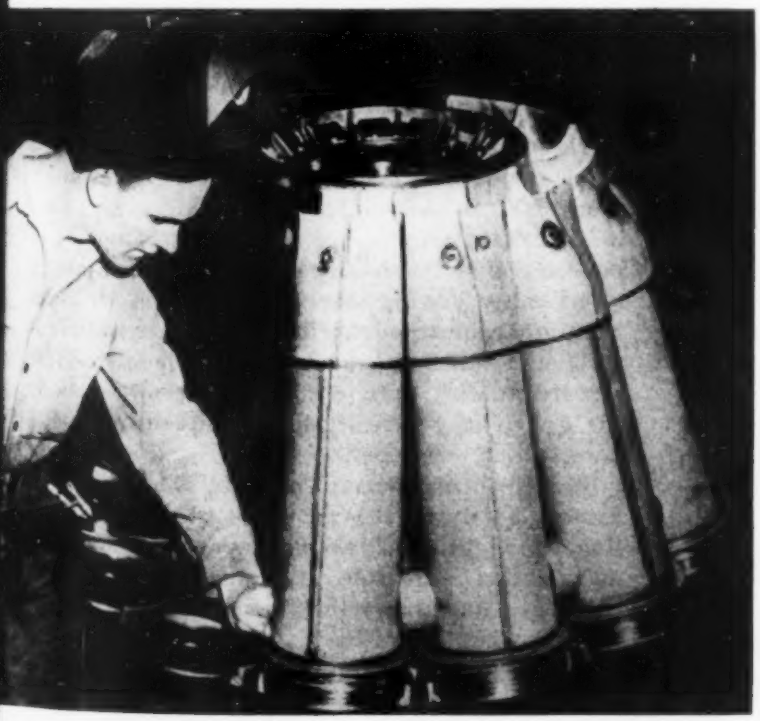


Fig. 6 — Nesting Inconel Combustion Tubes (for G.E. Engine in "Shooting Star") in Fixtures Prior to Welding Together Into a Single Unit. Courtesy I.T.E. Circuit Breaker Co.

work, form, weld. I might be a little bit shy of such alloys from the fabrication standpoint. Inconel and such materials as 25-20 are very readily formed, very easily spot and seam welded (and that seems to be the favorite construction).

It might be of interest to mention that in their similar structures the Germans used simple calorized, low carbon sheet — that is, aluminum impregnated sheet. However, their units were very short lived, very bulky, and they had very complex cooling systems. Although they apparently did the job that they wanted to do (in some engines), we don't feel that that type of construction is going to be the ultimate answer on combustion chamber construction.

Franks — We understand that the Germans replaced the combustion liner in jet engines every 25 hr. That is a rather short time and we certainly want better life than that.*

Evans — So much for the time being for combustion chambers. From the combustion chamber gas is passed through what is known as a "diaphragm" which is nothing more or less than a series of guides or stationary vanes which direct the hot gas at the proper angle against the moving blades of the rotor turbine. Dr. Mohling, I would like you, if you don't mind, to tell us some of the history of the development of diaphragm sections for the aircraft turbocharger.

Mohling — Supercharger diaphragms were originally made of Type 316 stainless (18-8 Mo) fabricated sheet. However, there were a lot of troubles from warping and cracking of welds, so in cooperation with General Electric our company brought out a cast diaphragm of 25-20 which worked very well, even though 25 chromium, 20 nickel (balance iron) is weaker than 18-8 Mo.

Badger — On jet engine nozzle diaphragms there is rather a different problem than on the vanes for turbo superchargers in that the efficiency of that particular part of the equipment is very important and any loss through unnecessary friction or incorrect directional flow of gas is very detrimental to the over-all action of the engine. Accordingly, the sand castings that were widely used for the turbo supercharger did not have sufficiently accurate spacing of the blading, sufficiently accurate form or sufficient smoothness on the air foil section to make them acceptable. As a result, fabricated nozzle diaphragms have been used in jet engines. Speaking generally, at one time these were fabricated of sheet — the separate blades are made individually, and then assembled in the diaphragm. Subsequently, forgings or precision castings have been used and welded into sheet shroud bands, or precision castings alone have been assembled by welding. For forgings, Type 347 (18-8 Cb) and Type 310 (25-20) stainless have been used. For fabricated sheet, Type 310 has been used both for the vanes and the shrouds. For castings, Vitallium (or the modified Haynes-Stellite No. 21 alloy, of which I spoke before as a sheet lining material) has been used, as well as Type 310 stainless.

Evans — Mr. Mochel, would you care to comment on diaphragms?

Mochel — Mr. Badger has already mentioned the problems we met in the Westinghouse engines. We use shroud bands — both inner and outer — of 25-20, with holes punched through it to support the blade. We have from the very beginning used precision cast blades for the stationary diaphragm vanes. We originally used the modified Vitallium that Mr. Badger referred to, although the 25% chromium, 20% nickel alloy seems to be a little more ductile and may be able to meet various service conditions better than the other. At any rate it is now being actively investigated. I think Mr. Johnson has something to add.

Johnson — I don't know whether Mr. Badger pointed out that we are using a fabricated diaphragm on the jet engine and a forged nozzle blade — that is a drop forging of Type 347 stainless (nominally 18% Cr, 8% Ni, 1% Cb).

Evans — Incidentally, when we say 25-20 we mean the standard A.I.S.I. alloy Type 310 which has been used in a number of applications to resist high temperature and corrosion for a good many years. One of the points that we want to bring out in this discussion is that we are making use of materials that we already know a good deal about.

We are leaving diaphragms. Then we come right up against our primary problem which is turbine wheels and buckets (or blades). This rapidly rotating unit is the limiting bottleneck in the design of the really high temperature equipment — and even of all the turbines that we have talked about so far. The centrifugal stresses, caused largely by the weight of the disk in rotation, are higher there than in any other part. The deformation allowable is lower, and they are expensive to build — that is at least one reason why we want these wheels to last a long time. We try to be as kind as we can to the rotating parts by keeping our working temperatures as low as possible. However, efficiency runs up rapidly as gas temperatures go higher and higher. Particularly in the simple unit such as the jet engine and the gas turbine design that Mr. Mochel talked

*Editor's Note — In contrast to the opinion held by American aviators who have met German jets in combat, American metallurgists generally believe the German engines were constructed of inferior materials.

Fig. 7 — Graphical Representation of Test Programs to Determine Properties at a Given High Temperature

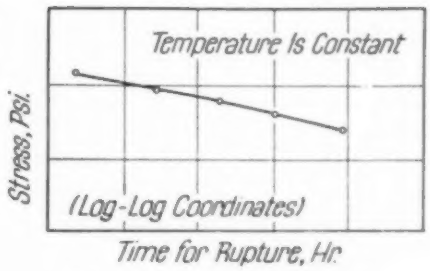


Fig. 7*a* — Stress-to-Rupture Plot, Single Temperature

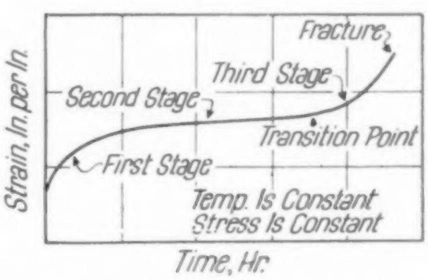


Fig. 7*b* — Plot of Typical Creep Test

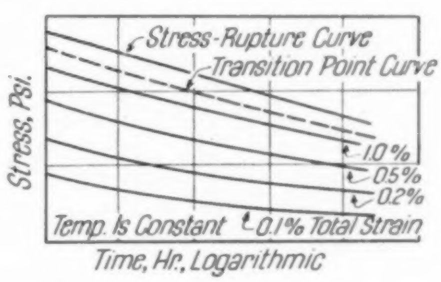


Fig. 7*c* — Curves for Designers

about we can't take too much of the heat generated in the combustion chamber away from the gas before it hits the turbine. Therefore, temperatures of the blades and rotors are apt to be very high. I would like to ask Mr. Cross to help us with an explanation of some of these problems and to describe briefly the tests by which we are attempting to evaluate suitable material for these rotating parts.

CROSS — I would like to emphasize an idea that Mr. Mochel previously mentioned and that is that there are four factors that must be considered in evaluating material for high temperature service — the four shown outside the square of Fig. 1. These are stress, temperature, expected service life, and the permissible deformation during service life. We must know all four of these items before we can properly evaluate a material. If you disregard one of them, you are likely to make a disastrous error.

In this gas turbine field, for the first time, we have had an opportunity to run tests for nearly the same length of time as the expected service life of the equipment being considered. The service life of both the wheels and buckets in the turbo superchargers is short. However, the material must not rupture. Clearances are not too close, so there were no stringent requirements on permissible deformation during this short life.

Consequently, "stress-rupture" tests were used to evaluate material for this service. A series of test specimens was loaded at a series of different stresses at the temperature of interest. If the unit load was above a certain critical figure the test piece would eventually break, and the time required (the "rupture life") and the elongation at rupture were measured. Log-log plots of stress versus rupture time were prepared, and these permit useful interpolations and extrapolations to be made for each alloy, and also comparisons between the rupture strengths of different alloys.

For long-time gas turbine service, such as in a marine or locomotive turbine, the stresses are lower, and permissible deformations are considerably lower because the service lives are longer. These materials are evaluated by creep tests, wherein a series of specimens is subjected to a series of stresses, all sufficiently low so that rupture does not occur (or, if it does, only after a long time), and the time-deformation characteristics of each are determined by noting the rate of deformation at specific time intervals and the total deformation at those same time intervals.

Combining stress-rupture test data and creep test data we can prepare charts for the use of the designing engineer which relate the four factors of stress, temperature, allowable deformation, and the expected service life. This we are doing for most of the important materials that are now being considered for turbine wheels and buckets, not only for turbo superchargers but also for gas turbines, for engines for aircraft propulsion, and for long-time service power units.*

In addition to the above, the fatigue properties are also important. Some fatigue failures have occurred in these pieces of high temperature equipment, and since these materials have low damping capacities, the fatigue resistance is important and it is being determined on most of them.

EVANS — Thank you. I think next it might be of interest to have Mr. Franks review for us the high temperature material situation, specifically in relation to alloys fairly well known before the advent of these so-called superalloys.

FRANKS — The discussion so far on the properties of the high chromium, high cobalt, high nickel materials has given little information about the recently developed high temperature alloys. All of you have known for a long time that

*EDITOR'S NOTE — A more comprehensive discussion of the tests and their interpretation by the designer is given in C. T. Evans's article in *Metal Progress* for November 1945, entitled "Wrought Heat Resisting Alloys for Gas Engine Service".

so-called stainless steels of various types have been used at elevated temperatures. These uses have had little or nothing to do with the present situation for the simple reason that material, say, in a furnace part, a tube sheet or the like could deform a considerable amount without destroying its utility or shutting the equipment down. The problem in connection with metals for the jet engines and gas turbines has been entirely different. The materials for these engines were required to retain their dimensions at high temperature just as ordinary steels do when a gear, for example, operates at room temperature. So, the problem of retention of dimensions — that is, lack of deformation — when heated to the high temperatures of combustion gas was the problem that confronted the metallurgist.

Around 1940 or thereabout, when the interest in these materials became great, the strongest material for high temperature use (with the exception of the Haynes Stellite alloys) was Type 316 stainless steel, ordinarily spoken of as 18-8 moly, although its average composition was more like 17% chromium, 12% nickel, and 2% molybdenum.

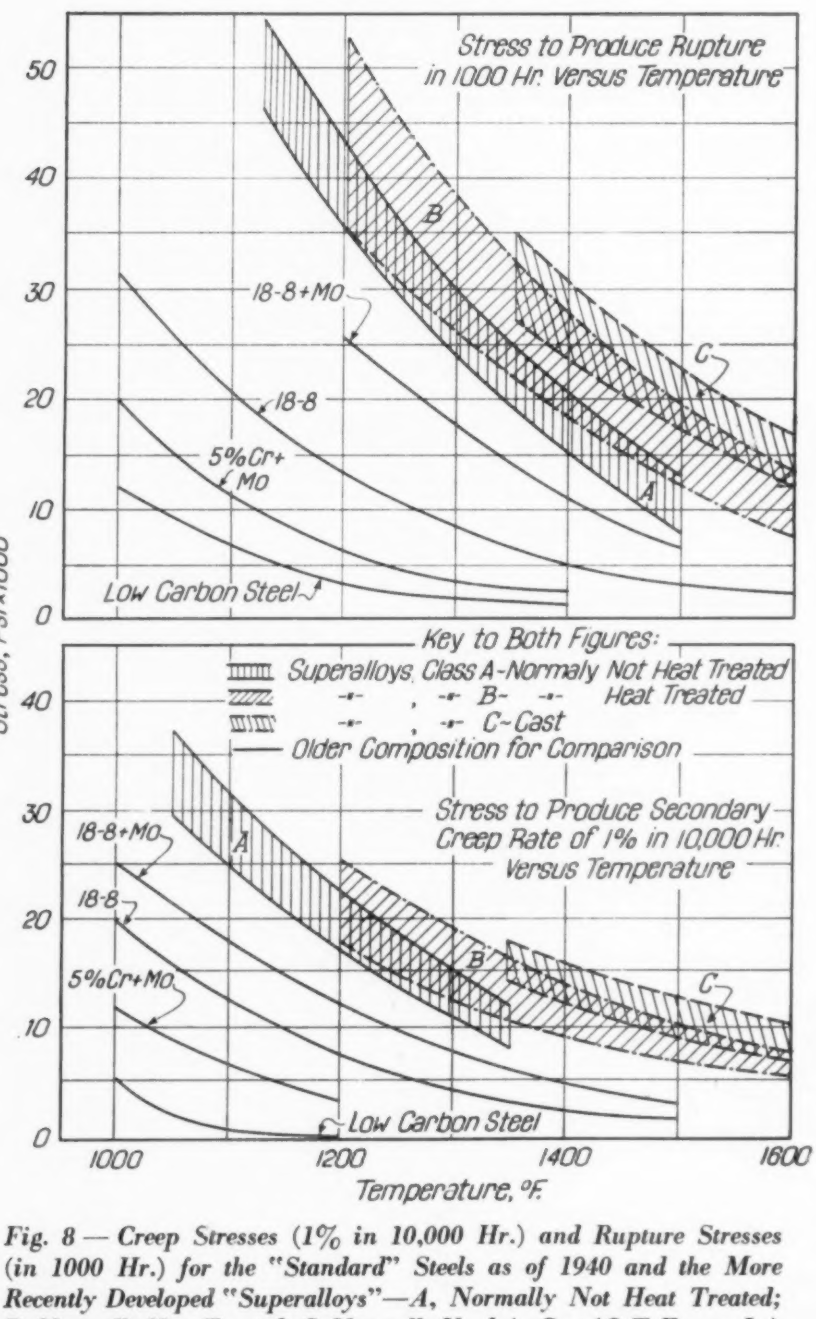


Fig. 8 — Creep Stresses (1% in 10,000 Hr.) and Rupture Stresses (in 1000 Hr.) for the "Standard" Steels as of 1940 and the More Recently Developed "Superalloys"—A, Normally Not Heat Treated; B, Normally Heat Treated; C, Normally Used As-Cast (C. T. Evans, Jr.)

It may not seem important to you now, but strange as it seems, that was the exact situation. This austenitic steel, even without fortification with molybdenum, had a creep strength at the high temperature of gas turbine operations that was considerably above that of ordinary steel, but even so the strength of the metal was far too low. Now just to give you an idea of what has happened since 1940 I would call your attention to a diagram made by our chairman (Fig. 8). This diagram shows the high temperature characteristics of low carbon boiler steel, the 5% Cr-Mo steel adopted by the refinery industry for still tubes handling corrosive crudes, the simple 18% chromium, 8% nickel stainless steel and the 18-8 moly, all in advancing order in the lower left section. Horizontal ordinates are temperatures and vertical ordinates are stresses. The four lines represent average values for the alloys current in 1940. You will notice that directly above the curve for 18-8 moly there are three distinct areas marked *A*, *B* and *C*. Area *A* represents conditions for what are classed as superalloys used without heat treatment. Area *B* gives the range of stress for superalloys that may be improved by preliminary heat treatment, whereas the best test figures of all are in *C*, for superalloys used in the as-cast condition. It can be seen that in general a considerable improvement of the strength of materials has been achieved during this five-year period since about 1940. Metallurgically speaking, there has certainly been progress in improving the strength of materials extending into the range from about 1400° F. up to 1600.

Table I — Physical Tests of Timken's 16-25-6 Alloy

Mark	Condition	Tensile Strength	0.2% Yield	Elongation in 2 In.	Reduction of Area	Modulus of Elasticity	Hardness: Brinell	Hardness: Rockwell
A	1-in. bar, hot rolled	117,000	70,000	41%	62%		210	C-20
B	A, tempered 12 hr. at 1300° F.	118,000	66,000	36	51		210	
C	A, cold worked (stretched) 20%*	148,000	112,000	21	41	28,200,000	285	C-32
D	A, solution treated (2150° F., water quenched)	109,000	52,000	49	71		185	C-5
E	D, tempered 12 hr. at 1500° F.	113,000	56,000	32	39		210	
F	D, cold worked (stretched) 20%*	142,000	95,000	26	50	32,500,000	260	C-27
G	Supercharger wheels (Forged to 1300° F., tempered at 1250° F.)	125,000 to 150,000	90,000 to 115,000	10 to 20	10 to 30			
	Above tests were made at room temperatures; those below were tested at temperatures noted.							
H	A, tested at 1300° F.	67,000	37,000	39	43			
I	A, tested at 1500° F.	40,000	30,000	49	67			
J	C, tested at 1300° F.	78,000	64,000	21	32	14,000,000		
K	C, tested at 1500° F.	45,000	37,000	30	41	10,000,000		
L	D, tested at 1300° F.	59,000	29,000	20	23			
M	D, tested at 1500° F.	43,000	27,000	40	50			
N	F, tested at 1300° F.	80,000	70,000	11	15	14,900,000		
O	F, tested at 1500° F.	48,000	42,000	9	13	13,800,000		
P	G, tested at 1500° F.	55,000 to 65,000	—	15 to 30	15 to 40			

*Tempered 4 hr. at 1250° F. for stress relief.

EVANS — Thank you. It might be instructive to have Mr. Johnson of the General Electric Co. give us a "blow by blow" description, if you want to call it that, of the battle for improved materials in the large aircraft turbo supercharger.

JOHNSON — "Blow by blow". We first used common S.A.E. 2335 for the wheel (that was in 1918) and at the same time S.A.E. 6150 was the bucket material. Later 6150 was used for the wheel alloy. To follow through on the wheel, the next material selected was silcrome No. 1 (exhaust valve alloy), later 17W for its good stress-rupture properties. We then used Gamma Columbium, and finally Timken alloy 16-25-5, which has been outstanding in performance and the one that has been in major production throughout the war. Now then back to the bucket —

EVANS — What is the analysis of the Timken alloy?

JOHNSON — 16% chromium, 25% nickel, 6% molybdenum, low carbon, some nitrogen, manganese and silicon, and the balance iron.

EVANS — I think it is interesting to point out that Mr. Franks noted that 18-8 with molybdenum was the best high temperature material prior to the advent of these so-called superalloys, and here we have another outstanding high temperature material containing a notable percentage of molybdenum.

JOHNSON — Following through the development of bucket materials: After S.A.E. 6150, silcrome No. 1 came to play its part. Then we used a British alloy, K.&E. 965; after that 17W, and later S-495 — all of which were forged alloys. Then came cast Vitallium which assumed the role of the main production material for the turbo supercharger buckets.

EVANS — We could stop and specify these analyses in more detail. I think 17W is one you might describe, Bob — or is it still restricted information?

JOHNSON — The analysis is common property. It had approximately 14% chromium, 19% nickel, 2.5% tungsten, 0.5% molybdenum, carbon around 0.40% and the balance iron.

EVANS — I think that Gamma Columbium is another one that you might tell about.

JOHNSON — That was very much the same as 16-25-6. However, instead of hav-

ing 6% molybdenum we used 3% of columbium to replace that much molybdenum, the carbon was raised and the nitrogen was left out. There were some problems in this substitution, for it was somewhat more difficult to weld and to machine. Physical properties were very good, though.

EVANS — It is hard to draw sharp distinctions in this whole picture, but I think probably that 17W, Gamma Columbium and Timken's 16-25-6 were certainly among the first of the alloys to come into the classification of superalloys. I think that it would be helpful if Mr. Cross would take up where Mr. Johnson left off and describe the general characteristics of that first class of so-called superalloys.

CROSS — As Mr. Johnson said, the 17W alloy is a nickel-chromium-iron alloy and was used for the supercharger wheel. Alloys in group *A* normally used without heat treatment, as shown in Fig. 8, are essentially chromium-nickel-iron alloys with sizable additions of one or more of the elements molybdenum, tungsten, titanium and columbium. The Timken alloy, 16% chromium, 25% nickel, 6% molybdenum, balance iron, also falls in this class. The alloys with properties between 17W and Timken's are 19-9 W+Mo; 19-9 DL; E.M.E.; and 234A5; they are all essentially alloys containing about 19% chromium, 9% nickel, and molybdenum and tungsten in amounts up to about 1.5%. They have small columbium and titanium additions. The 234A5 alloy has 4% of manganese replacing a like amount of nickel. They appear to be better than the straight 18-8 with molybdenum only, as an addition.

These alloys are usually used in wheels for turbo superchargers and gas turbines with operating temperatures up to about 1200° F. Their best properties are obtained when they have been worked (forged or pressed) in the temperature range of about 1200 to 1400° F. After such work, yield strengths at 0.2% offset are obtained in

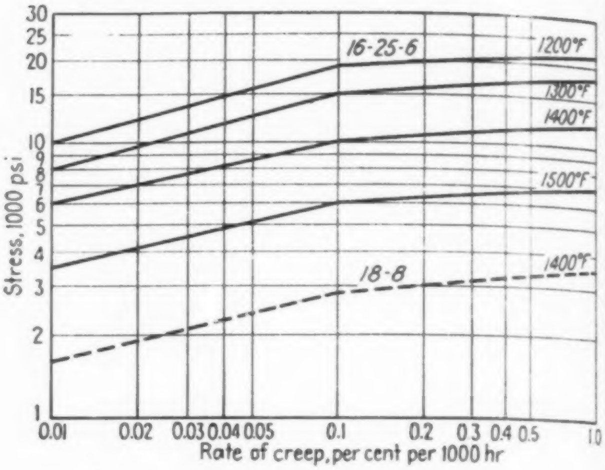


Fig. 9 — Creep Rates of 16-25-6 Alloy in Forged and Solution Treated Condition

room temperature tests of 60,000 psi. and up. Rupture strengths at 1200° F. and 1000 hr. are about 35,000 psi. and up, and for 100 hr. rupture, about 45,000 psi. and up.*

Looking at the class *B* alloys of Fig. 8 there are several alloys which by proper working can be heat treated to produce about the same properties that are obtained in the alloys just mentioned. The British use Nimonic 80, which is principally a nickel-chromium alloy, having very little iron but some aluminum and titanium added for precipitation hardening. In this country, we have used hardenable Inconels — Inconel W and Inconel X. These alloys are principally nickel, containing about 14% chromium, whereas the British alloy contains about 20% chromium. Inconel X, which has recently been suggested, contains about 1% columbium in addition to the titanium and aluminum, and this seems to increase the ductility. These heat treatable alloys will produce slightly higher properties than some of those that are worked (Class *A*) and 100-hr.

*EDITOR'S NOTE — Martin Fleischmann, metallurgical engineer for Steel & Tube Division of Timken Roller Bearing Co., has furnished the following information about its patented 16-25-6 alloy, as well as values in Table I and Fig. 9 and 10:

Alloy 16-25-6 was first produced in 1942 in response to a demand for turbo supercharger wheels. More than 6000 tons of it have been shipped since then, mostly produced in 25-ton arc furnaces and cast into 14 to 21-in. round corrugated ingots.

Its composition is based on the firm's successful 16-13-3 composition. About 16% chromium and 1% silicon were judged necessary for corrosion and scaling resistance; molybdenum — the best alloy for high temperature strength — was limited to 6% for steelmaking reasons, and 25% nickel was required to insure an austenitic structure free from delta constituent. Nitrogen was also introduced, rather than carbon, for its stabilization and strengthening effects.

Composition range is as follows: Carbon 0.12% max., nitrogen 0.10 to 0.20%, manganese 2% max., silicon 1% max., chromium 15 to 17%, nickel 24 to 27%, molybdenum 5.5 to 7.0%.

The alloy is intrinsically too hard to be rolled in blooming mills suitable for low alloy steels, so ingots are reduced to 8-in. blooms in hydraulic presses, then hammered to 5-in. blooms, and finally rolled from there on down in toolsteel mills. Maximum forging temperature is 2000° F. "Cold working" effects start as the metal cools past 1700° F.; physical properties of the billet, bar or upset disk, therefore, depend on finishing temperature and also upon amount of reduction in the last squeeze — facts thoroughly exploited in the die design and forging practice specified by General Electric Co. for supercharger wheels.

Tempering a forging or hot rolled bar changes its physical properties slightly; 70 hr. at 1200 or 1300° F. increases the hardness about three points on

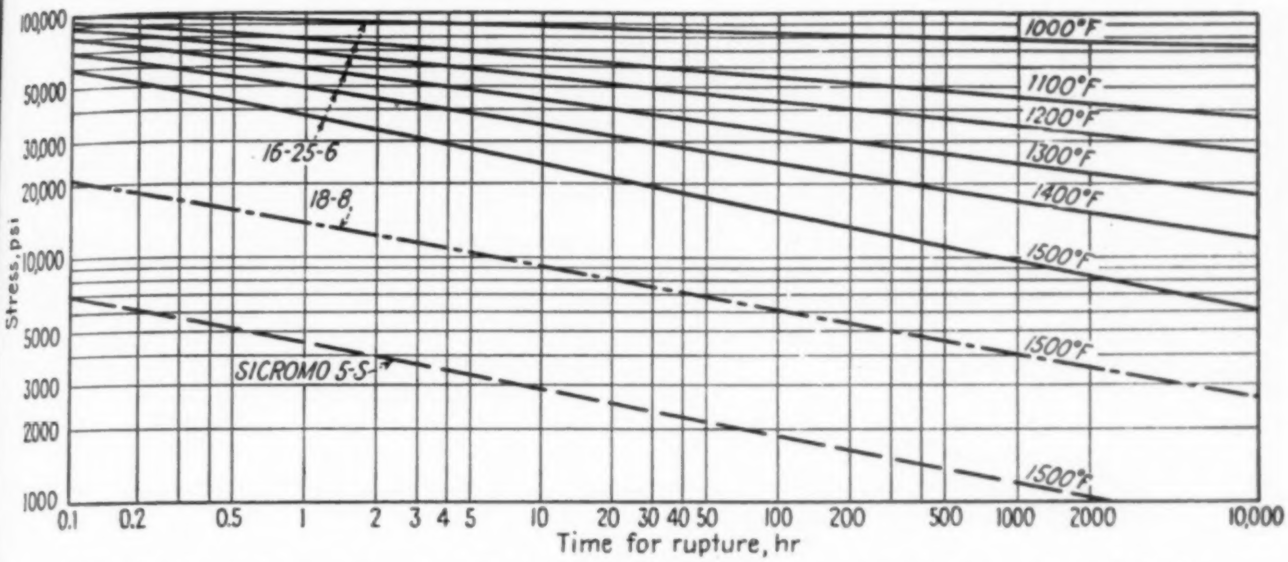


Fig. 10 — Stress-Rupture Curves for Timken's 16-25-6 Alloy in Forged and Solution Treated Condition. Comparison lines are drawn at 1500° F. for austenitic 18-8 and pearlitic Sicromo 5-S (5% Cr, 0.5% Mo, 1.5% Si). Drawings for Fig. 9 and 10 reproduced from The Iron Age, *Jan. 24, 1946*

rupture times at stresses in excess of 50,000 psi. at 1200° F. have been obtained.

Evans — We have arbitrarily kept the superalloys under the three groups of Fig. 8. Mr. Cross, I think, has given us a good general picture of the first two groups. He mentioned a lot of analyses and a lot of alloys about which some in the audience might be curious. When the floor becomes open, we hope that if you want more information on any of these you will speak right up. We will supply the data if we have it and if we can. The second class of alloys, called class *B* on that diagram, as Mr. Cross indicated, are more highly alloyed and are characterized by being heat treatable — that is, they obtain their best properties after heat treatment. I will ask Mr. Franks to tell us more about some of the compositions within that classification.

Franks — I think that Mr. Cross put the emphasis on the class *A* alloys exactly where it should be — and that is that some help from the standpoint of working has been needed to make those alloys usable. The range of temperatures used — roughly 1200 to 1400° F. — leaves us in a

the Rockwell C scale; 1400° F. leaves the hardness unchanged; 1500 to 1700° F. reduces the hardness about 6 points in 70 hr.

Microstructure of hot rolled 1-in. bars is fine grained austenite (nonmagnetic) with fine spheroids of a second constituent arranged in bands (the result of ingotism). This constituent may be put in solution by heating to 2150° F. or above. Such homogenized austenite (hardness C-5) shows characteristic age hardening effects on long tempering, taking 10 hr. at 1400° F. to reach its maximum of C-18, 2 hr. at 1500° F. to reach C-13 (which hardness remains constant indefinitely), while 1600° F. induces overaging (softening) of 3 points below its hardness maximum after 30 hr. at heat. Such temperings produce a fine diffuse precipitate, observable at 1000×, as expected, but no growth of the austenitic grain size.

Representative physical properties are shown in Table I, page 107. Tempering after cold work relieves internal stress, precipitates fine excess constituent and then spheroidizes the precipitate; the relative influence of these changes on strength and hardness depends on temperature, time and previous history of the sample; 20 hr. at heat seems to be enough to produce stability for temperatures up to 1500° F. Hardnesses of 20% stretched samples C and F of Table I (originally hot rolled and solution treated, respectively) after 20-hr. temperings are as follows:

Tempering	Sample C	Sample F
None	C-32	C-27
1200° F.	C-29	C-29
1300	C-27	C-27
1400	C-24	C-23
1500	C-22	C-20
1600	C-20	C-17
1700	C-17	C-16

Stress-rupture curves of test pieces water quenched from 2150° F. are shown in Fig. 10; for long rupture times these values are not improved by previous cold work or precipitation hardening if temperatures are above 1200° F. Likewise, lowest creep rates are when the metal is in the homogenized (solution treated) condition; see Fig. 9. Rotating fatigue tests at elevated temperatures give endurance limits above the stress for rupture at 10,000 hr. for the corresponding temperature.

Coefficients of thermal expansion are as follows:

70 to 200° F.	8.4×10^{-6} in. per in. per °F.
70 to 600	8.85
70 to 1000	9.2
70 to 1400	9.5

quandary as to how to describe it. It cannot be said to be "cold work", for this ordinarily means pressing or flanging at room temperature or only slightly warmed. On the other hand "hot work" means (for steels, at least) rolling or forging at temperatures above 1700° F., where the metal glows with color. What shall we call this new range where working *strengthens* hot metal? Some compromise, and say "hot-cold"!

At any rate the primary object of the work done on class *B* alloys has been done to develop enhanced strength by heat treatment which may or may not be helped by working. As a matter of fact, the working of alloys of class *B* does not help the high temperature strength when the alloys are in the neighborhood of 1300° F. or higher. Best results then are definitely obtained by the use of a heat treatment. I think that is an important point to remember.

Two of the compositions with the lowest alloy content — wrought materials — that have been developed in this class have been the ones known as N153 and N155.

Evans — While Russell is putting the composition on the blackboard I would like to make just one comment on the class *A* alloys. The impression should not be given that those materials — normally not heat treated — cannot be used unless they have been cold worked, hot-cold worked, or warm worked, or whatever you want to call the processing at 1200 to 1400° F. Where it is required that the high temperature machinery have a very long operating life, such as the power gas turbine designed for at least 10 years' service, or the diesel engine turbo supercharger which is designed for indefinite service (some of them have been in the field, continuously operating, for nearly five years) these alloys, when properly handled, worked and stress relieved, do have remarkable stability and very low creep rates within the working temperature range of 950 to 1200° F.

Franks — This N155 alloy contains 20% chromium, to give good oxidation resistance at high temperatures, with 20% nickel, 20% cobalt, 3% molybdenum, 2% tungsten, and 1% columbium. Quite a galaxy of good metals! This metal has been produced with a low carbon content and with a relatively high carbon content — that is, in two ranges, one around 0.10 to 0.20% and the other from 0.30 to 0.40%. It can be readily hot worked. It is extremely strong even though it has relatively good hot workability. Naturally the hot working has to be carried on slowly as compared to the rates permissible for the stainless steels. It can be welded and it represents a "well balanced" alloy. Its stress-to-rupture in 1000 hr. at 1500° F. is 16,500 psi., in comparison with 14,200 for Vitallium and 7000 psi. for 18-8 Mo, Type 316 steel. Other details of its physical and mechanical properties as well as creep and stress-rupture tests are given in Tables IV, V and VI* [pages 114 to 116].

The N153 alloy contains the same elements as N155 with the exception that the chromium content is about 16%, the nickel around 15%, cobalt about 12%, with molybdenum 3%, tungsten 2%, and columbium 1%. N153 has also been developed in both high and low carbon contents and it, like the N155 type of alloy, has high temperature strength with good fabricating characteristics.

Evans — Thank you. That just opens the discussion on the class *B* alloys. We are not going into too much detail at this time, but I do want to mention one of the older compositions that is heat treatable — that is, gets its properties by heat treatment — and which has done a very interesting and useful piece of work. Who can help me out on Hastelloy alloy B?

Badger — Hastelloy alloy B has been on the market something over 10 years. It was developed for corrosion resistance to hydrochloric acid solutions and sulphuric acid solutions up to the boiling point. It was available in the wrought form but caused considerable difficulty in rolling and forging operations. When the need for parts to work at high temperature developed, we found that this alloy, fully annealed after rolling, carried in excess of 60,000 psi. at 1500° F. After suitable aging treatment — which, of course, reduced the ductility considerably — the strength would be in excess of 80,000 or even 90,000 psi. at 1500° F.

Although this alloy was available at the beginning of the war, the problems of producing drop forgings from it satisfactorily had not been worked out. That problem was attacked at General Electric's River Works and adequately solved, so that alloy B was used throughout the production of the G.E. I-16 engine for the turbine blades. It did a very creditable job. It was also set up for the standard alloy for the big blades on the I-40 unit. However, the forging difficulties were sufficiently great and the forging facilities of the type necessary were pretty well tied up on other work. Consequently no I-40 engines were made in production with forged Hastelloy alloy B blades, although it was the standard material for the job, and the experimental work had been satisfactorily done with it.

Incidentally, Hastelloy B is the peculiar alloy of the whole group in that it carries no chromium at all. Its analysis is (in round numbers) molybde-

*Editor's Note — Data for these tables were released by the Governmental censor after the January meeting in Cleveland.

num 28%, iron 5%, nickel 66%, carbon 0.10%. All of those elements are available right here on this continent. From that point of view, it was attractive at one time during the war when foreign shipping and imports of metal from Africa, India and South America were in serious trouble.

EVANS — Mr. Badger, do you think it would be proper to mention the oxidation problem on Hastelloy alloy B?

BADGER — Yes. Due to the fact that there is no chromium in it, there is a definite limitation to the top temperature at which it can be operated satisfactorily. For periods up to 300 to 400 hr. the top temperature is 1400° F. For periods of operation from 1000 to 5000 or 10,000 hr., top temperature is between 1300 and 1350° F. Otherwise oxidation, with ensuing loss of molybdenum, is likely to occur.

CROSS — May I cut in here? I think it should be mentioned, in addition to what Mr. Franks says about N155 in the ranges of carbon up to about 0.40%, that some work has been in progress at Massachusetts Institute of Technology for several years for the Navy on carbon contents for N155 up to 1.00 to 1.25%. Very promising results have been obtained.

EVANS — Am I correct in believing that those are cast compositions?

CROSS — Yes, they are cast; that is true. They have the same general composition as the N155 that Mr. Franks recounted.

EVANS — They do not belong in this class *B* then, but rather in class *C*. Class *B* is intended to be made of those compositions that can be wrought. Of course, many of them can also be used as castings, as we will show later on. However, there is another group of alloys in class *B*, and I would like it if Mr. Mohling would describe them for us.

MOHLING — We developed a number of alloys of the same general composition as N155 with higher tungsten, molybdenum and columbium. Carbon is in the medium range. The main advantage of these alloys is that they have been produced in very large scale, cast into ingots up to 16 in., and forged and rolled under commercial conditions. They are also easily forgeable as drop forgings, like buckets; large forgings up to 1000 lb. have been made under the hammer. These alloys have been held under test in our laboratories for several years and we have tests on them up to 15,000 hr. showing that they are stable over long periods at the range of about 1300 to 1500° F. I think that is all that needs be said about them just now.

EVANS — I am not going to let you get away that easily! I wish you would do what Mr. Franks did for us (if you have no objection to doing so) and show the limits of, let us say, your alloy S495 and then it will not take you long to tell how you modified it for the other alloys.

MOHLING — Carbon is aimed at 0.40 in all three alloys, S495, S590, and S816. Chromium in S495 is 14%, and 20% in the other two. Nickel is 20% in all three. S495 has no cobalt; S590 has 20% cobalt and S816, 43%. Molybdenum, tungsten, and columbium are each 4% in all three alloys. Details of composition and thermal properties are given in Table II. Both S590 and S816 are precipitation hardening alloys and optimum properties are secured from a solution treatment at 2300° F., and a water quench, followed by aging at least 10 hr. at 1400 or 1500° F. Higher temperature solution treatments give slightly better rupture and creep strengths at the cost of lower ductility. We do not recommend strengthening the solution treated structures by cold work.

Both these alloys are very hard and stiff at forging temperatures; top forging temperature is 2300° F.; reheatings may be 100° F. lower. Long soakings are necessary to counteract the low heat conductivity. The alloys have no hot short range, but "work hardening" starts at a high temperature, so frequent reheatings are necessary for forgeability.

Machining is somewhat difficult and should be done at low feeds and speeds, using a positive cut. For drilling, the solution treated condition (soft-

Table II — Alloys S590 and S816

	S590	S816
Analysis: Carbon	0.40%	0.40%
Silicon	0.65	0.40
Manganese	1.65	0.50
Chromium	20.	20.
Nickel	20.	20.
Cobalt	20.	43.
Molybdenum	4.0	4.0
Tungsten	4.0	4.0
Columbium	4.0	4.0
Iron	35.0	4.0
Melting point (approx.)	2400° F.	2400° F.
Specific gravity	8.34	8.66
Coefficient of expansion (in. per in. per °F.)		
70 to 600° F.	7.6×10^{-6}	6.6×10^{-6}
70 to 1000° F.	8.0	7.1
70 to 1400° F.	8.3	7.7
70 to 1800° F.	8.4	8.3
Thermal conductivity, B.t.u. per hr. per ft.² per in. per °F.		
at 120° F.		83
at 400° F.		104
at 725° F.		121
at 1110° F.		147

Table III — Tensile Properties of Allegheny Ludlum Alloys S590 and S816

Mark	Nature	Ultimate Strength	0.02% Yield	Elong. 2 In.	Reduction	Modulus of Elasticity
	Alloy S590; 0.505-in. test pieces tested at room temperature					
A	As rolled★	152,000	80,000	19	25	
B	Solution treated and aged†	140,000	42,000	20	19	29,000,000
C	Precision cast	84,000	37,000	4	10	
	S590, tested at high temperatures (pulling rate: 0.05 in. per min.)					
D	B, tested at 1200° F.	81,600	49,000	27	31	
E	*B*, tested at 1350° F.	65,750	46,000	25	30	16,000,000
	Alloy S816; 0.505-in. test pieces tested at room temperature					
F	As rolled★	175,000	73,000	39	45	
G	Solution treated and aged†	159,000	68,000	21	20	31,000,000
H	Precision cast	112,000	59,000	5	13	
	S816; tested at high temperatures (pulling rate: 0.05 in. per min.)					
I	G, tested at 1200° F.	120,000		17	22	
J	G, tested at 1350° F.	98,900		15	22	15,000,000
K	G, tested at 1500° F.	78,250		12	21	
L	G, tested at 1700° F.	46,200		14	17	

★Alloys work harden even at very high temperatures; strength in the rolled condition therefore depends very largely on the finishing temperature.

†Typical results; average of many tests. Test pieces held 1 hr. at 2300° F., water quenched, annealed 16 hr. at 1400° F., air cooled.

est) appears best, but for other operations many shops prefer the age hardened condition. This is due to the fact that the rate of work hardening which is very high in the soft (solution treated) condition, is quite low in the aged condition.

Data from stress-rupture tests and creep tests are charted in Fig. 9 and 10 for S590 and S816 respectively. Note that the stress-rupture curves for wrought test pieces are a little higher than for precision cast test pieces, but the latter retain good strength at very high temperatures — at least for 1000 hr. Also notice that S816 has much superior high strength properties to S590; for example, the curve for 1000-hr. rupture for S816 is practically the same as the 100-hr. curve for S590. Short time tensile tests listed in Table III, above, also show this superiority.

I also have some scattered data on endurance of S590 and S816, as well as their toughness, and hardness after high temperature aging:

	S590		S816	
Charpy impact, V notch				
at 70° F.	8 ft-lb.		26 ft-lb.	
at 1500	27		45	
Endurance limit, 10^8 cycles				
at 1200° F.	—		68,000 psi.	
at 1500	—		33,000	
Hardness	Brinell	Rockwell	Brinell	Rockwell
Quenched	241	C-20 to 22	255	C-26 to 27
Aged 16 hr. 1500° F.	302	C-30 to 32	311	C-32 to 33
1700° F.	269	C-24 to 27	293	C-29 to 31
1900° F.			277	C-26 to 28

I should add that the data in the tables and figures presented include results obtained by University of Michigan, Battelle Memorial Institute, General Electric and Westinghouse laboratories, as well as Allegheny Ludlum's.

Evans — Thank you. You have heard a lot about heat treatment in the last few minutes. We are of the opinion that the whole routine of heat treatment of materials is one of the most important developments of this whole research into superalloys. We had no idea when we started to work on this problem about five years ago that we could heat treat these alloys and get the extremely high stress-rupture and creep properties that they were eventually found to possess.

Let us finish up our discussion of the three classes of alloys by asking Mr. Badger to describe briefly the characteristics of class *C* of Fig. 8, which are the highest strength compositions and are cast materials. Mr. Badger.

Badger — Class *C* alloys in general are cobalt-based, Stellite type alloys which Mr. Franks has mentioned. They are chiefly used in the form of castings made by the precision casting process.★ Due to the fact that they are alloys of low iron content their ductility is, in general, not as high as those of the other alloys that we have been talking about, and the changes made in the older standardized alloys in order to make them suitable for the war program were primarily for improving their ductility at high and low temperature. This is done chiefly by reducing the carbon content.

Class C alloys are precipitation hardening alloys, and they maintain their strength properties by the gradual and constant precipitation of strengthening phases within the microstructure at the temperature of

★Editor's Note — This was fully described and illustrated in "Supercharger Buckets Mass Produced by Precision Casting" by Arthur E. Focke in *Metal Progress* for September 1945.

operation. In certain instances, the physical properties are changed much faster if they are aged for a period of 50 hr., more or less, before the testing is carried out.

However, in general, aging (at appropriate temperature) lowers the ductility and increases the fabricating problem, so that in high production none of these alloys have been used in the "precipitated" condition — they have been used either as-cast or after machining or other operations in which cold work was involved after a solution anneal at the lower end of the annealing range.

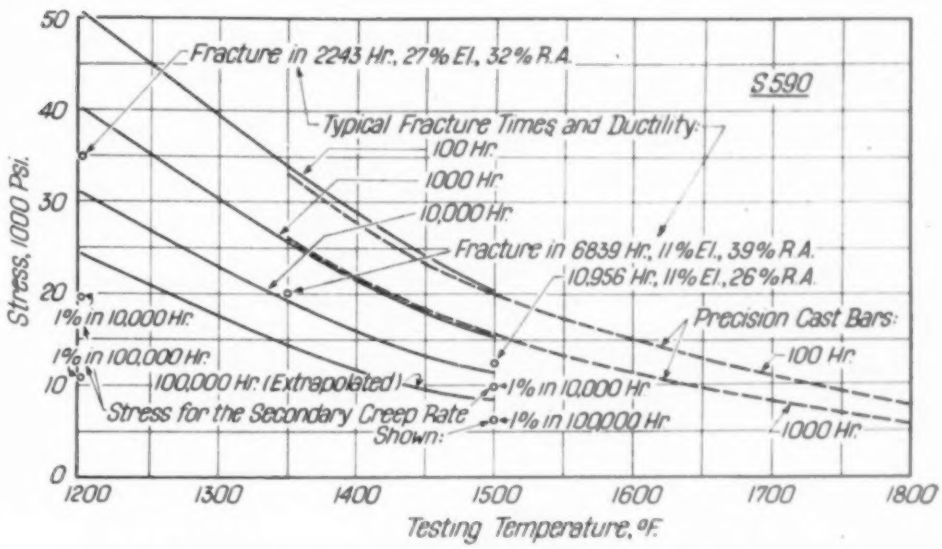


Fig. 11 — Stress-Rupture Tests and Secondary Creep Rates for Allegheny Ludlum Alloy S590, Rolled Bars 0.252 In. Diameter, Quenched From 2300° F. in Water and Aged at 1400 to 1500° F. for 16 to 50 Hr.

It has been known for a long time that the cast structure has superior creep strength to the wrought structure at elevated temperatures. However, it was not appreciated, I think, that this information could be used to fine advantage on the turbo supercharger until stress-rupture tests were made on Hastelloy alloys A, B and C, with the same analyses of each grade in cast and in wrought form. This test showed that the short time strength of the wrought material is very much higher than the short time strength of the casting, but the stress-rupture life on a log-log plot of stress versus time to failure showed a very steep slope on the wrought material, whereas it was a very nearly horizontal line on the cast material. This indicated that the wrought material had a much faster loss of life than the casting.

The reason for this has been thought to be that, at the temperature involved — which was 1500° F., the temperature of operation of the bucket — the grain boundary material is actually weaker than the material within the grain. Consequently, any method by which you could reduce the amount of grain boundary material would be helpful in increasing the strength at that temperature. (It is interesting to note that a patent has been taken out on a treatment to improve the creep strength of high temperature alloys by "annealing" near the melting point — which, of course, is influential in increasing the grain size and reducing the amount of the grain boundary material.)

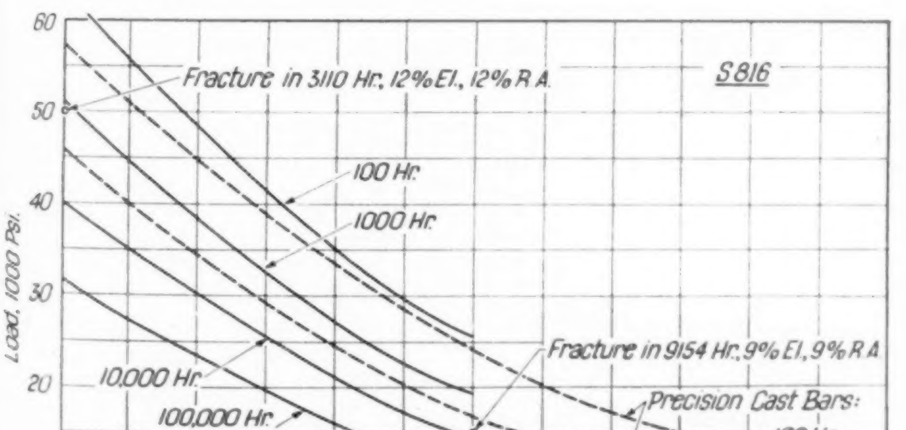


Fig. 12 — Stress-Rupture Tests (and Secondary Creep Rates at 1500° F.) for Wrought and Precision Cast Test Pieces of Allegheny Ludlum Alloy S816, Solution Treated at 2300° F., Quenched in Water and Aged 16 Hr. at 1400 to 1500° F.

However, there has been one definite drawback of coarse grain size in cast-

Table IV — Properties of Chromium-Cobalt Alloys*

	Cast Alloys			Forging Alloys		
Common name: N.D.R.C. reference: Haynes Stellite name:	Vitallium NR 10 HS 21	61 NR 60 HS 23	6059 NR 63 HS 27	422-19 NR 12 HS 30	X-40	Low carbon N 155 NR 66 Multimet
Analysis: Chromium	28	28	28	28	28	20 *(a)*
Molybdenum	6	—	6	6	—	3
Tungsten	—	6	—	—	7.5	2
Nickel	2	2	35	16	12	20
Cobalt	Balance	Balance	Balance	Balance	Balance	20
Carbon	0.20 to 0.30	0.40 to 0.50	0.40 to 0.50	0.40 to 0.50	0.40 to 0.50	0.10 to 0.20 *(b)*
Density, g. per cm.^{3}	8.2986	8.5385	8.2077	8.3137	8.6078	8.1985
Coefficient of thermal expansion (in. per in. per °F. $\times 10^{-6}$)						
70 to 600° F.	7.83	7.64	7.53	7.70		8.70
70 to 1000° F.	8.18	8.18	8.04	7.91		9.10
70 to 1500° F.	8.68	9.24	8.67	8.42		9.77
Endurance strength in psi. of as-cast specimens at 10^7 cycles except those marked (2.5) meaning at 2.5×10^8 cycles						
At 1200° F.	44,000	44,000	41,000			66,000 *(c)*
At 1500° F.	33,000	38,000 (2.5)	30,000 (2.5)			32,000 (2.5)
Short-time tensile properties at 1500° F., cast test pieces aged 50 hr. at 1350° F.						
Ultimate strength	59,000	58,500	51,200	64,000	59,600	
Yield (0.2% offset)	49,000	40,600	38,200	47,600	44,500	
Elongation in 2 in.	6.8	7.8	10.1	3.0	10.3	
Reduction of area	12.0	12.7	14.4	3.4	14.1	
Modulus	16.8×10^6	23.5×10^6	18.7×10^6	25.6×10^6	19.3×10^6	
Short-time tensile properties at 1800° F., tested as-cast						
Ultimate strength	33,300	33,100	33,400	36,300		
Elongation in 2 in.	35.0	32.0	24.0	24.0		
Reduction of area	52.4	40.6	50.3	33.7		

Notes: *Data derived from reports of investigations conducted for the O.S.R.D., as well as from investigations of the Haynes Stellite Co., Westinghouse Electric Co., and General Electric Co.

(a) Plus 1% columbium and 0.14% nitrogen.
(b) Also a high carbon variety is made (0.25 to 0.35%).
(c) Endurance specimens of N 155 were given no solution treatment but were aged 50 hr. at temperature of test prior to stressing.

ings, and that is the matter of low endurance limit that has already been mentioned. These coarse-grained castings definitely have a lower high temperature fatigue; this offsets to a certain extent their higher stress-rupture and creep properties. Consequently, to design satisfactory structures for operation under stress at these high temperatures there has to be some compromise. Where better damping characteristics can be built into the equipment, these coarse-grained, or relatively coarse-grained, castings definitely *can* be used to obtain the fullest benefit of their stress-rupture and creep properties.

Mr. Cross has mentioned the carbon content of N155. All these Cr-Ni-Co-Mo-W-Fe alloys have higher stress-rupture properties as the carbon goes up. That is as true of Vitallium as it is of N155; however, ductility is impaired as carbon increases, and we want to avoid anything which makes assembly and fabrication of the units more difficult. This is very important, particularly in high production. Consequently, we have tried to maintain a balance of the elements so the elongation of these alloys, as-cast, is at a minimum of 8 to 10% when tested at 1500° F.

I would like to give you a short résumé of the physical properties and particularly the chemical analyses of these cobalt-base alloys. I will use as a starting point the chemical analysis of Vitallium, or Haynes Stellite No. 21 alloy, which I gave before as molybdenum 6%, chromium 28%, carbon 0.20 to 0.30%, nickel 2%, low iron, balance cobalt. There are two alloys in which tungsten is employed instead of molybdenum; one is No. 61 alloy (or Haynes Stellite No. 23) which is like No. 21 just quoted except that it carries 6% of tungsten instead of molybdenum and the carbon is up to 0.40 to 0.50%. Another alloy with tungsten is X40 with 7.5% tungsten (somewhat higher than No. 61); 12% of the cobalt is replaced with nickel and carbon is again 0.40 to 0.50%.

Both these alloys show some tests which are remarkably high — very good properties —

Table V — **Creep Test Data Obtained From O.S.R.D. Investigations on Chromium-Cobalt Alloys Cast by Haynes Stellite Co.**

Alloy	Stress, Psi.	Deformation Upon Loading	Creep Rate, % per Hr. at 500 Hr.	1000 Hr.	1500 Hr.	2000 Hr.	Total Deformation, % at 500 Hr.	1000 Hr.	1500 Hr.	2000 Hr.
					Tests at 1350° F. *(n)*					
Vitallium	15,000	0.068	0.0003	0.00019	0.00007	0.0001	0.442	0.540	0.596	0.662
Vitallium	12,000	0.069	0.00013	0.0001	0.00008	0.00008*(a)*	0.220	0.275	0.318	0.338*(a)*
61	20,000	0.068	0.00036	0.00042	0.00063*(b)*		0.292	0.518	0.712*(b)*	
61	15,000	0.050	0.00025	0.00016	0.00014		0.234	0.310	0.379	
6059	20,000	0.070	0.00045	0.00047	0.00047		0.446	0.690	0.950	
6059	15,000	0.076	0.00044	0.00008	0.00008		0.405	0.479	0.519	
6059	12,000	0.042	0.000005	0.000002	0.000002	0.000002	0.135	0.137	0.140	0.140
422-19	15,000	0.075	0.00015	0.00007	0.00004	0.00003	0.262	0.320	0.342	0.360
422-19*(m)*	15,000	0.062	0.000184	0.000119	0.000073	0.000062	0.267	0.363	0.408	0.438
N155*(c)*	20,000	0.113	0.00031	0.000165	0.000125	0.0001	0.396	0.510	0.583	0.632
N155*(c)*	15,000	0.094	0.00032	0.000268	0.000361	0.000612	0.366	0.563	0.651	0.893
N155*(l)*	20,000	0.092	0.00062	0.00062	0.000725	0.000895	0.671	0.975	1.318	1.724
N155*(l)*	15,000	0.073	0.000116	0.00079	0.000053	0.000038	0.254	0.298	0.327	0.351
N155*(l)*	12,000	0.058	0.000042	0.000025	0.000017	0.000013	0.115	0.130	0.141	0.148
					Tests at 1500° F. *(m)*					
Vitallium	7,000	0.036	0.0001	0.000205	0.00011	0.00009	0.127	0.208	0.296	0.344
Vitallium	7,000	0.046	0.000224	0.0001	0.00006	0.000065	0.285	0.354	0.405	0.439
Vitallium	7,000	0.039	0.00027	0.00014	0.000135	0.0001	0.215	0.348	0.417	0.500
61	12,000	0.080	0.000285	0.00011	0.000085	0.000035*(e)*	0.506	0.608	0.657	0.682*(e)*
61	12,000	0.035	0.000022	0.000062	0.000024	0.000024	0.176	0.201	0.205	0.222
6059	12,000	0.078	0.00019	0.00018	0.000080		0.305	0.500	0.575	
6059	12,000	0.075	0.00041	0.000198	0.000132	0.00013	0.678	0.815	0.894	0.963
422-19	12,000	0.069	0.00021	0.000068	0.000035	0.000035	0.430	0.487	0.507	0.523
422-19	12,000	0.060	0.000191	0.000079	0.000061	0.000046	0.397	0.453	0.489	0.524
N155*(d)*	10,000	0.054	0.0002	0.00025	0.00062		0.308	0.415	0.607	
N155*(d)*	8,000	0.065	0.000063	0.000043	0.000047	0.000048	0.157	0.180	0.206	0.230
N155*(d)*	7,000	0.041	0.00005	0.000035	0.000025	0.00002	0.137	0.154	0.174	0.182
N155*(l)*	12,000	0.061	0.000122	0.000107	0.000124	0.000168*(f)*	0.181	0.238	0.292	0.323*(f)*
N155*(l)*	9,000	0.064	0.00020	0.00027	0.0003	0.00038*(g)*	0.184	0.310	0.452	0.627*(g)*
					Tests at 1600° F. *(k)*					
Vitallium	10,000	0.120	0.00033	0.00013	0.00013	0.00013	0.790	0.900	0.980	1.036
Vitallium	7,000	0.089	0.000125	0.000044	0.000044	0.000044	0.258	0.308	0.330	0.353
Vitallium	5,500	0.063	0.000036	0.000031	0.000031		0.122	0.130	0.163	
61	9,000	0.058	0.0002	0.0001*(h)*			0.300	0.332*(h)*		
61	7,000	0.024	0.00005	0.000036	0.000036		0.173	0.193	0.207	
61	5,500	0.035	0.000045	0.000025	0.000025	0.000025*(i)*	0.105	0.127	0.152	0.164*(i)*
6059	11,000	0.060	0.00036	0.00031	0.00026	0.00025	0.627	0.784	0.922	1.05
6059	9,000	0.050	0.00002	0.000013	0.00001	0.00001	0.143	0.153	0.162	0.165
6059	7,000	0.045	0.00005	0.00003	0.00002	0.00001	0.141	0.158	0.169	0.171
422-19	12,000	0.080	0.00027	0.00023	0.00011	0.00028	0.700	0.815	0.880	0.980
422-19	11,000	0.051	0.000085	0.00002	0.00002	0.00002	0.284	0.301	0.313	0.325
422-19	9,000	0.044	0.000065	0.000015	0.000015	0.00001*(j)*	0.230	0.249	0.256	0.260*(j)*

Notes: *(a)* Data for 1800 hr.
(b) Data for 1300 hr.
(c) Specimens hot worked and aged (carbon 0.15%).
(d) Specimens water quenched and aged (carbon 0.15%).
(e) When discontinued at 2780 hr., rate: 0.000023% per hr.; total deformation: 0.70%.
(f) Data for 1750 hr.
(g) When discontinued at 3400 hr., total deformation was 1.34%; rate was increasing.
(h) Data for 833 hr.
(i) When discontinued at 2184 hr.
(j) When discontinued at 2207 hr. the rate was less than 0.00001%; elongation: 0.26%.
(k) Aged 50 hr. at 1600° F. before testing.
(l) Specimens water quenched and aged (carbon 0.34%).
(m) Aged 50 hr. at 1500° F. before testing.
(n) Aged 50 hr. at 1350° F. before testing.

Table VI — Stress-to-Rupture in 1000 Hr.

Type	1000°	1100°	1200°	1300°	1400°	1500°	1600°	1700°	1800°	2000°
			Pre-War Alloys *(a)*							
S.A.E. 1015	12,000	6,500	2,700	1,500	900					
502 (5% Cr; Mo)	19,000	11,000	6,000	3,250	2,000	1,500				
446			4,000	2,800	1,700	1,200	800			
304 (18-8)			11,500	9,250	6,500	3,500	2,750			
347		27,500	20,000	12,500						
316 (18-8; Mo)			25,000	18,000	11,000	7,000	4,000			
310	30,750	20,500	13,250	7,750	4,500	3,000	2,250			
			Chromium-Cobalt Alloys *(b)*							
Vitallium			44,200	27,000	15,000	14,200	13,200	10,000	7,000	4,200 (10 hr.)
61						21,800	12,000	11,500	5,400	
6059						18,400	12,000	8,600	6,800	
422-19						21,700	14,800	11,500	7,100	3,000 (100 hr.)
X-40						23,400	18,000	14,500	9,800	4,000 (100 hr.)
N155 *(c)*						16,500		4,800	2,800	

(a) Quoted by C. T. Evans, Jr., in *Metal Progress*, November 1945, p. 1091. *(b)* Data derived from reports of investigations conducted for the O.S.R.D. and N.A.C.A., as well as from investigations of the Haynes Stellite Co. *(c)* Low carbon (0.10 to 0.20%), solution heat treated.

but for some reason these tungsten-bearing alloys are rather variable. Other work that has been done with tungsten and its alloys shows rather wide variation in the properties. It is only fair to say that Vitallium, too, has this unwelcome characteristic, although the variation in the physical properties, test to test, is not as wide as it is for No. 61 or X40.

There are three variations of Vitallium still using molybdenum. In one of them, one quarter of the cobalt has been replaced with nickel. It is called 422-19, or Haynes Stellite No. 30. For a cast material it shows surprisingly uniform properties under test. In the other (alloy No. 6059 or Haynes Stellite No. 27) one-half of the cobalt has been replaced with nickel. Both of these have from 0.40 to 0.50% carbon. At one time during the war, when there was possibility of a cobalt shortage, No. 6059 alloy carrying about 32% cobalt and 32% nickel looked like a very favorable method of stretching our supply of cobalt. However, its room temperature properties, as far as strength goes, are considerably lower than those of Vitallium although its long-time high temperature properties are in the same class — perhaps slightly higher.

I would like to emphasize a few of the properties that can be expected from these alloys, and that are listed in Tables IV, V and VI. These data are derived from reports of investigations conducted for the National Defense Research Committee of the Office of Scientific Research and Development, and the National Advisory Committee for Aeronautics, as well as from investigations of the Haynes Stellite Co.

No. 6059 shows a room temperature strength of from 80,000 to 90,000 psi. The other alloys in the group that I have mentioned break at 100,000 to 110,000 psi. Tensile strength of these alloys at 1350° F. (short-time tests) runs from 66,000 psi. for No. 6059 to 75,000 to 80,000 psi. for the others in the group. Yield at 0.2% offset varies from 50,000 to 60,000 psi. in all these alloys when aged 50 hr. at 1350° F. and tested at that temperature. At 1500° F. the short-time strength of these alloys is in the neighborhood of 50,000 to 60,000 psi., and the yield strength at 0.2% offset is 38,000 to 48,000 psi.* (In most of these instances the lower strength I am quoting is for the 6059 alloy with a base of half nickel, half cobalt.)

One of the particularly interesting characteristics of these alloys is the drop in modulus of elasticity at the higher temperatures. For instance, No. 21 alloy (Vitallium) has a modulus of 24.2×10^6 at 1350° F.; at 1500° it has dropped off to 16.8×10^6. Haynes Stellite alloy No. 23 (which is the tungsten variety of Vitallium, No. 61) has a modulus of 27×10^6 psi. at 1350° and only 23.5×10^6 at 1500°. Alloy 422-19, however, has very uniform modulus

*Data issued Feb. 25 by Haynes Stellite Co., taken from a report to O.S.R.D., indicate that the Cr-Co alloys do not change much in hardness after long stays at high temperatures. Following are the Rockwell hardnesses (A scale) of cast specimens after 1 hr. and 100 hr. at temperature noted.

Alloy	Temperature	1 Hr.	100 Hr.
Vitallium	1350° F.	A-65	A-71.5
61	1350	A-66	A-71.5
6059	1350	A-62	A-66.5
422-19	1700	A-67.5	A-72
X-40	1700	A-67	A-71
N155 (as forged)	1500	A-56	A-59

right up to 1500°: test results show 24.8×10^6 at 1350° and 25.6×10^6 at 1500° — which is as close as you can expect to check modulus figures at those temperatures. However, at 1600° F. the figure starts to drop off, and it is 17.3×10^6 psi., about in line with the other alloys in this family.

The stress-rupture figures on Vitallium for 1000 hr. run 14,200 psi. at 1500°. The other alloys No. 61, 422-19 and X40 run somewhat higher than that, varying from 21,800 to 23,400 psi.

EVANS — At how many hours?

BADGER — One thousand hours, 1500° F. Creep rate at 2000 hr. is of interest to design engineers. In most of these alloys at 1350° F. and 15,000 psi. the creep rate is in the neighborhood of 0.0001% per hr. However, we have an interesting figure on Haynes Stellite No. 21 (Vitallium) in which material aged at 1350° before test showed 0.0001% per hr., while material aged at 1500° had a creep rate of 0.0003% per hr. That is an indication that the material has aged sufficiently at this temperature of 1500° so that it over-ages during the creep test, whereas it is brought up to its maximum hardness by aging at 1350° and does not over-age on further stay at 1350°.

It might be well to say before closing that most of the I-40 buckets were produced of Vitallium (or Haynes Stellite No. 21 alloy) by precision casting because of the speed with which that program had to be built up. Precision castings are particularly adaptable to new alloys (of which important properties are not known) for new designs, for prompt changes, and for high production. Much work on very intricate types of blading and sections, including hollow designs, would be impossible without the precision casting method.

EVANS — Thank you. We have tried to give the audience a general picture of the alloys we now have available. Before we close the general discussion those of us that are actually building gas turbines will tell you what we are using in our gas turbines — that is, jet engines, gas turbines and the like. I wonder if Mr. Johnson would start.

JOHNSON — I believe that I did mention before that we are using Timken alloy 16-25-6 Cr-Ni-Mo, on the wheel.

EVANS — That is for a jet engine, I suppose.

JOHNSON — That is right. On the bucket, we are using cast Vitallium. Some work on Hastelloy B is being done on this part. For liner material we use Inconel; for the high temperature sheet material we are using 18-8 columbium (Type 347).

EVANS — Mr. Mochel, how about the Westinghouse units.

MOCHEL — So far as the disks are concerned we have used the forged 19-9DL alloy almost entirely. We had some experience with Cyclops 17W and Gamma Columbium at the start, but more recently our work has been almost entirely with 19-9DL. We have done a considerable amount of experimentation in trying out various amounts of cold work and determining the useful properties of these modifications. Today, we are still satisfied with 19-9DL as it is performing in our present designs.

I have already intimated that we have used cast blades entirely for the stationary vanes or nozzle diaphragm blades — first of Vitallium and more lately we have had some experience with 25-20 Cr-Ni.

In the moving blades, our work has been divided largely between two materials, or rather two types of materials. We have used a good many forged blades and machined blades of an alloy of our own manufacture which many of you will recognize when I use the term K-42-B (roughly speaking, 42% is the minimum of nickel, 20 to 22% cobalt, 18 to 20% chromium, 14% iron, hardened with 2¼% titanium and some alumi-

Table VII — Properties of Westinghouse Alloy K-42-B
(From "Westinghouse Metals and Alloys for Communications and Electronic Equipment")

Typical composition	42% Ni, 22% Co, 18% Cr, 14% Fe, 2.2% Ti
Melting point	2530° F. (1390° C.)
Density	0.296 lb. per cu.in. (8.2 g. per cc.)
Thermal conductivity	0.027 cal./cm.²/cm./°C./sec. at 20° C.
	0.047 at 500° C.
Coefficient of expansion	12.5×10^{-6} from 20 to 100° C.
	14.5×10^{-6} from 20 to 400° C.
	15.3×10^{-6} from 20 to 600° C.
Oxidation in air at 1500° F. (800° C.)	
Gain in 100 hr.	0.016%
Gain in 200 hr.	0.021
Gain in 400 hr.	0.025
Solution treatment	1 hr. at 1750° F., water quench
Hardness	150 to 200 Brinell
Aging treatment	24 hr. at 1300° F., air cool
MECHANICAL PROPERTIES AT 70° F., AGED TEST BARS	
0.01% yield	84,500 psi.
0.02% yield	88,500
0.2% yield	105,500
Ultimate strength	158,000
Elongation in 2 in.	29%
Reduction of area	37%
Elastic modulus	30,000,000 psi.
Brinell hardness	260 to 330

num). Modifications of this basic alloy and attention to grain size have given us recently the highest fatigue life of any materials we know of — fatigue limits as high as 83,000 psi. at 1200°. This alloy will probably serve us up into the range of 1350 to 1400° F. Other properties are shown in Tables VII and VIII.*

Table VIII — Short-Time High Temperature Tests on K-42-B
(Quenched from 1750° F. and aged 24 hr. at 1300° F.)

Temperature	Yield	Ultimate	Elong.	R.A.
70° F.	90,500	157,000	29%	49%
1000	88,800	134,700	26	49
1200	84,400	117,200	9	13
1350	82,000	97,000	4	7
1500	52,000	54,000	10	13
1600	29,000	29,000	45	56

We have used a good many cast blades, both the cast Vitallium and also the Stellite alloy No. 23 composition described by Mr. Badger in which the molybdenum is replaced by tungsten. Our experience with cast blades is excellent. We started out with drop forged blades in one design, an earlier model; we changed to blades machined from rectangular bar stock in a later one; our more recent models are using cast blades entirely. We believe that there is much to recommend the cast blade for the moving element, especially when one considers the higher temperature ranges.

Evans — Thank you. For the Elliott Co.'s diesel engine turbo supercharger that I mentioned, the top conditions of 1020° F. with 28,000 psi. maximum stress were met by the alloy known as 19-9 W-Mo, developed by Universal Cyclops Steel Corp. It contained approximately 0.10% carbon, 19% chromium, 9% nickel, 1.25% tungsten, around 0.40% molybdenum, columbium, and titanium. It is quite a complex composition and the microstructure is partly ferritic. This alloy gave us such good service in that turbocharger that when we found it had adequate creep qualities at 1200° F. we used it in the first power gas turbine that was shown in Fig. 5 (see page 102). That turbine, as I believe I mentioned, operates at 1200° F. and 8000 psi. maximum stress and we hope that it will last for a long time — 10 years or thereabout.

The new turbines which we are building — three 3000-hp. stationary gas turbines — are designed to operate at 1400° F. and 8000 psi. maximum stress. We will use S-590 — that is, the alloy with 20% chromium, 20% nickel, 20% cobalt, 4% molybdenum, 4% tungsten, 4% columbium that Dr. Mohling described. We will use that in the rotor wheels and blades. We are using some lower compositions including N155 in the diaphragm and the blades, as well as 25% chromium, 12% nickel, slightly modified, in the castings which are not particularly under stress.

That is a brief picture, I think, of the alloys that are used and where they are used. You can see that our respective firms do not always agree about what is proper to use. It is a typical American metallurgical picture; we progress in different directions at once, and we all stick together in some other lines. I think, however, that we should definitely leave you with the impression that we are not at all satisfied with the present alloy situation. The research during the war, although it was very comprehensive, was quite largely negative in that — perforce, due to the urgency — we had to grab some alloy compositions out of the air, or go under the rug for them, or just try anything!

I think that it would now be interesting, at the close of this formal meeting, to have Mr. Cross tell us briefly what is planned in the line of future research.

Cross — All during the war, under a N.D.R.C. project, Climax Molybdenum Co. and Vanadium Corp. of America have been working on new types of alloys. It seems logical that the alloys of the future must necessarily be those with higher melting points than the matrix alloys which we are now using. Those alloys will lean heavily upon the group chromium, columbium, tungsten, molybdenum, tantalum, thorium, titanium and platinum. Considering the general properties of these alloys and their availability, chromium seems the one most likely to be used.

Following this assumption Climax Molybdenum Co. worked on and tested all the logical binary and ternary chromium-rich alloys. From their work on chromium-iron-molybdenum alloys they find that the most usable range contains about 60% chromium with a range of 15 to 25% iron and 25 to 15% molybdenum. Only a limited amount of work has been done on these alloys so far, and the work is continuing. The preliminary stress-rupture data up to 1600° F. definitely show that the chromium-base alloys are considerably higher in stress-rupture properties than the cobalt-base alloys now known.

The Vanadium Corp.'s staff have been working on chromium-nickel-cobalt alloys containing considerable amounts of tungsten — as much as 18 to 20% — with additions of boron, beryllium and

*Editor's Note — A full account of this interesting alloy was printed in *Metal Progress* in March 1942 ("A New Alloy for Working at High Temperature", by P. H. Brace).

vanadium. These alloys also show promise at 1600° F. As Mr. Evans said, the approach has been largely empirical, except for the work just described, but work is now under way at the Naval Research Laboratory, at the N.A.C.A. Engine Laboratory here in Cleveland, and at Battelle Memorial Institute in an effort to find out *why* these alloys are as good as they are. We know how good they are; we have been measuring their properties for four years. Now we are going to try to find out what makes them tick. If we can, we will then design better ones.

EVANS — I can see some in the audience that know as much or more about this subject than we do, and we would now like to have an open discussion and have them participate in it. If you have anything that you want to say at all, come to the microphone that Mr. Mochel has on the right. If you just have a question, I will try to hear it and repeat it into the microphone so that everybody else can hear it. Do I have any questions from the floor?

QUESTION — What was the duration of the fatigue test on K-42-B?

MOCHEL — I made the statement that at 1200° F. we had determined fatigue limits as high as 83,000 psi. Duration of test was 100,000,000 cycles.

QUESTION — Is 100,000,000 enough?

EVANS — I think that I might mention on that point that these alloys' high temperature fatigue curves do not flatten out very fast. As a matter of fact, I am not sure that work has progressed far enough to say there is a true endurance limit — that the S-N curves do flatten out.

CROSS — Some of them do, some of them don't.

EVANS — But mostly don't! Is that right?

CROSS — Many do not.

QUESTION — Is it practicable to control grain size for high strength properties — reliably?

EVANS — Dr. Mohling, would you care to comment on grain size control?

MOHLING — It is very difficult, for one thing. In wrought alloys it can be *prevented* by stress relief before heat treatment. I am unable to comment on cast alloys.

EVANS — You say that you control grain size by stress relief before heat treatment. That is new to me.

FRANKS — Well, I think one answer to that question is that we cannot control grain size at high temperatures. We increase grain size very materially by heat treating at very high temperatures to get the effect of a solution heat treatment.

EVANS — I would take a different line, for we *have* to control grain size in these alloys. Otherwise how will you know that you can get consistent properties? I don't think you meant it just that way.

FRANKS — My point is that you can't use a solution heat treatment on these alloys without increasing grain size considerably.

EVANS — Isn't that in itself a control? You know if you go to a certain temperature you get a certain range of properties which are undoubtedly influenced by the grain size produced at that temperature.

JOHNSON — Can't the grain size be controlled, Mr. Evans, by solution treatment just as is done with any austenitic material? For instance if you cold work 18-8 a definite amount and then heat it to a definite temperature for a definite time, you get a definite average grain size. If you want a certain set of creep properties or stress-rupture properties in one of the superalloys, you might heat it to, say, 2100 or 2200° F., quench it from there, and follow it with some definite annealing or aging treatment.

EVANS — That is true. However, it is my experience that the control of grain size in this class of materials is just as difficult as in other commercial alloys, if not more so, and it follows the same general rules — the higher the solution heat treatment the larger the grain; the more you forge it the more chance you have for a fine grain, and so on. This is a very critical part of the whole picture. Undoubtedly, as the fundamental research described by Mr. Cross progresses we will get more and more information about grain size control in both the cast and the forged alloys. Now, in the forging alloys it seems that we have some chance. I would like to ask Mr. Badger what he thinks about controlling grain size in cast materials.

BADGER — The difficulty in controlling the grain size in cast materials is that these castings generally have very thin edge sections, down to as low as 0.020 in. Generally, those thin sections are going to have a relatively fine grain size anyway for they solidify rapidly. Naturally, the control of grain size in castings is a matter of metal temperature when pouring. But we are confined to some extent to the proper technique to fill those thin edges. Of course, it is possible to produce very fine grain size by centrifugal casting, but — for a variety of reasons, that I can't elaborate right now — that scheme has not worked out too satisfactorily.

EVANS — There are several important people who have questioned whether it is easier to control grain size in forgings than in castings. Your remark about centrifugal casting, therefore, is worthy of a little elaboration.

BADGER — Well, we have done quite a lot of

work at Kokomo on the centrifugal casting of these small parts, but the majority of it was confined to test bars. Generally speaking, the grain size in the centrifugally cast bars that we have made was definitely finer than that in the gravity cast bars or pressure cast bars. It is true that on cast turbine blades that have very wide differences in section thickness there is also a wide variation in grain size. We cannot get away from that except in parts that are reasonably constant in section thickness. For instance, the I-40 blade at one point is ¾ in. thick and at another point is only 0.030 in. thick. It is inevitable that there will be coarse and fine grain in that blade, especially when gravity cast.

Evans — Would you summarize the situation by saying that the cooling rate is a very important factor in controlling grain size? There are certainly other factors such as alloy composition, presence of inoculators and gas content — particularly the latter, for you will get a different grain size after vacuum melting than you will after ordinary melting.

Mr. Mochel, as a consumer have you found wide variation in the grain size of castings that you have purchased?

Mochel — I think every consumer will admit that he has found that. Personally, I think that the rate of cooling is probably the matter of first importance. In centrifugal casting a lower mold temperature has often been used, and maybe credit has been given to the *method* when it may have belonged to the temperature of the mold and the rate of cooling.

H. H. Harris, president, General Alloys Co. — I wish to emphasize that it is one thing to cast small supercharger parts, individually, by the lost-wax process, and quite another thing to make parts for a jet engine operating at 1500° F., plus, which must deliver 1000 hp. to the rotor, for the supercharger delivers only 100 or 200 hp., and operates at the moderately low temperatures of an engine exhaust.

Consider first the foundry problems: It is well known that in the lost-wax process the small electric furnace melts only enough alloy to fill an individual mold containing a few blades; at best the entire melt will weigh only a few pounds. It is inherent that procedures that may be accurately controlled in a large furnace, melting a ton of material, are difficult or impossible to control in a tiny furnace melting 1 to 10 lb. The result is a tremendous variation in grain size in the castings which in turn results in highly irregular ductility and ability to withstand fatigue failure, and this is accentuated by variations in surface-to-mass ratios inherent in the diverse forms being cast. Entirely apart from this is the wide range in pouring temperatures; optical pyrometer readings on molten metal cannot control grain size within desired limits. Unfortunately, no X-ray or test other than a destructive test reveals grain size.

Considering the great lack of experience with high temperature mechanisms in the jewelry, dental and bone-screw trades, many of the results expected from the lost-wax process were beyond reasonable expectations. They do, I believe, fall far short of what could have been done had seasoned experience with use and failures of high temperature alloys been brought to bear. It is inevitable, therefore, that in this drive for accurate dimensions in the castings — which is a fine talking point for the lost-wax type of process — reliability and uniformity of the metallurgical part have taken second place.

No thought is required to come to the conclusion that a metal which must be stiff and strong at very high operating temperatures must also be very hard and strong at forging temperatures, and be consequently relatively difficult to roll or forge accurately. Few mills are equipped to handle the stronger heat resisting alloys at the speeds, pressures and temperatures necessary. Desiring production, mills naturally prefer to compromise with alloys that roll easier. Such alloys then become "standards" to the salesman.

It is logical that new alloys can best be tested in cast form. Cast parts, besides being quite easy to make to accurate shape, are also quite easy to handle when experimental analyses are under study. Finally, accurate castings have great advantage in that they largely eliminate machining. Machining which removes the fine outer surface is undesirable, for this outer surface is exceedingly important when the proper casting technique is employed. It can, design permitting, be prestressed either in tension or compression, as the designer wishes. Lastly a casting can be more free from warpage in use than a forging.

On the other hand, mill melting practice is generally superior to the foundry's. Commercial sand castings almost invariably contain sand — or minor porosities resulting from combustion of bonding materials.

Worth the most vigorous emphasis is the importance of controlling grain size by proper inoculation and advanced casting practice. If there is anything which is certain about the reaction of metal at high temperatures under stress, it is that grain size is one of the principal factors. Many silly statements are going the rounds about proper methods of controlling grain size, such as "centrifugal casting produces smaller grain size". Any elementary student should know that grain

size is a function of the rate at which the metal cools through its solidification range, and it doesn't make any difference to the casting whether the liquid metal is squirted into a mold centrifugally, with air pressure behind it, dropped off a balcony, or poured into a dry-iced sand mold — as long as that cooling rate is the same, the resulting grain size will be the same.

What this all boils down to is that it may be possible to "design" an alloy composition which should perform in a superior manner at high temperatures, but it is entirely another problem to *manufacture* these parts with a high degree of precision and uniformity of metallurgical and mechanical properties. So far the "experts" appear to have been paying most attention to precision of dimension, but the requirements also involve the highest degree of manufacturing *uniformity*. Here is where those who have spent a lifetime in developing high temperature alloys might help. Design based upon a knowledge of what happens to castings in the mold, and what stresses, restraints and thermal factors will influence them in service, is more important than much controversial metallurgy. More than a quarter-century experience in high temperature alloy mechanism has largely escaped jet and turbine air engine designers. The scrap pile gives eloquent testimony.

Evans — We certainly appreciate your comments, Mr. Harris, and we hope that you and your organization will continue the work that has started out so favorably. We will all get a lot of help from it. Thank you very much. Is there any other question from the floor, along this line or along a different one?

Question — What is the influence of dendritic structure on the grain size pattern and the resulting properties?

Franks — As a matter of fact, there is not too much known about the effect of dendritic structure, which almost invariably occurs in most of these alloys, but it is generally believed that the dendritic structure has a weakening effect.

Question — Is the precipitation reaction similar to what takes place in the age hardenable alloy duralumin?

Franks — The precipitation hardening which Mr. Badger referred to is definitely unlike that which takes place in the aluminum alloys. The aluminum alloys are very soft after the solution heat treatment; then by mere aging at room temperature or by heating a short time at a moderate temperature a new constituent precipitates from the solid solution and the metal becomes much harder and stronger. These high temperature alloys contain a precipitate after they are held at the elevated temperatures. They may or may not increase in hardness. Usually the precipitation effect does bring about some increase in strength. However, these high temperature alloys cannot be made soft, and then later treated to become very hard. This precipitation effect is noticeable after extended periods at high temperatures.

Evans — Mr. Franks, you said that the precipitate does not form in these alloys very rapidly. I would qualify this in the case of the "S" group of compositions that Dr. Mohling developed. They harden in a matter of a few hours. Your statement is true of the N155 and allied alloys.

Mochel — Mr. Chairman, I do not think we should let this impression about the rate of pouring, mold temperatures and the matter of grain structure pass without making reference to the very excellent work that Dr. Nicholas J. Grant has done at Massachusetts Institute of Technology. This audience should not be allowed to go with the feeling that no thought and study have been given to this problem, because Dr. Grant did an excellent piece of work along that line, although many are not yet acquainted with it.

Evans — Dr. Grant, would you please come forward and give us a résumé of this work you have been doing at M.I.T.?

Grant — In the course of a great deal of work we were doing with high carbon alloys, we investigated the effects of carbon content on rupture properties and ductility. To study the experimental results we plotted the rupture life on a logarithmic scale against carbon on a linear scale, and got what was essentially a straight-line plot whereby a maximum strength is reached at some particular carbon content. In the N155 type of composition that has been mentioned here, it falls at about 1.0 to 1.1% carbon. In the Vitallium type, it is a little higher, about 1.1 to 1.2% carbon.

While we were investigating this effect, we noticed that some of the plotted points in certain alloys failed to fall anywhere near this average line, and we naturally wondered why some of these cast alloys showed such extremely erratic properties. We therefore began to control casting conditions very, very closely — that is, the temperature of the mold, the temperature of the metal, and so on. We found that we could explain the discrepancies shown by certain alloys by variations in the metal and in the temperature of the mold. This seemed so interesting that we continued this work; we investigated four different alloys — the Vitallium alloy with low carbon, the No. 6059 alloy which is essentially medium carbon, and two higher carbon alloys — one in the N155 system at about 1% carbon and the other a modified Vitallium at about 1% carbon.

From this work, we are convinced that as the mold temperature or the pouring temperature increases, the grain size of the resulting casting increases very rapidly. We also checked the effect of pouring temperatures on the spacings between the adjacent carbide particles in the cast dendritic structure. Summarizing these results briefly, we were able to draw the relationship that as the grain size becomes progressively larger and larger, the rupture life increased very much. For example, if a certain stress-rupture test on a bar cast at 2650° F. (cast by the precision investment process under what we might consider ordinary casting conditions) gave a rupture life of 50 hr., we were able to get as much as 500-hr. performance from the same alloy under the same test conditions merely by raising the casting temperature up to 2825° F.! Furthermore, when we plotted mold preheat temperature against rupture life, or if we plotted grain size against rupture life, we found the same distinct relationship.

All of these things are interconnected very closely. When making precision castings it is extremely important to control metal pouring temperature and mold temperature. If you wish to change the investment material, you will probably have to change other casting conditions. If you change the size or shape of the particular parts, the grain size is affected — that is, if you cast a round bar section, you get one set of microstructural conditions; if you cast blades, where there is a high ratio of surface to mass and therefore greater area for nucleation, you will find for the same casting conditions a vastly different grain structure. Conditions which will give a coarse-grained material in a ¼-in. round cross section will give a much finer grain in a thin turbine blade. Grain studies on round tensile specimens do not carry over to turbine blades. When we realized that several casting variables are interconnected in an important way with grain size, we were capable of checking back to old castings of poor performance and related the structures to performance. When we did this, we were able to go back to the original curve of plotted data and made alloys that were reproducible.

I would like to bring up one other point that I thought of as I listened this evening and that is in connection with the aging of these particular alloys. We have recently been running extensive tests concerning this. I would like to suggest that we avoid generalizing on many of these alloys because it only leads to false impressions of what is actually going on. Vitallium, for instance, is a vastly different type of alloy from N155, and as much can be said for other interesting compositions. Some one or two of these families of alloys may show essentially no aging in an ordinary heating cycle up to 1500° F. — aging, that is, in the sense of change in strength, ductility or hardness of the alloy.

On the other hand, we have found fairly large volume changes in other alloys on ordinary heating at the rate of 4° per min. up to 1500° F. — volume changes which certainly indicate that there is some sort of internal reaction taking place, such as the precipitation of some phase. While you may not be able to measure the difference by ordinary hardness measurements, that isn't a true measure of aging unless you are using some test method which eliminates the effect of large carbides or other precipitated particles. For example, if you are covering fairly large areas in your hardness readings — as in a Brinell test — you may be measuring the effect of the carbide particles rather than the effect of aging in the austenitic matrix, for carbide particles are not affected by aging whereas austenite is. Depending on the carbon content, you may get highly erratic results, affected by the quantity of carbide that is under the indenter when the reading is made.

That, in general, is the gist of it. Again I would like to say that it does not pay to generalize. I think it is better if we speak specifically of individual alloys and definite test conditions. In some alloys aging does show up readily and in others it doesn't. In some alloys aging shows up in rupture life properties and in some it doesn't. We just can't generalize on that and make sense.

FRANKS — Dr. Grant, I think you have put this matter of aging very rightly. I think that the term "aging" is better than "precipitation hardening". As I understand precipitation hardening, it means a process that results in an actual increase in the over-all strength of the material by submicroscopic precipitates. These superalloys do not undergo that sort of change, as far as we know now.

EVANS — I think that Dr. Grant's remarks emphasized one point that all of us who have been working in this field want to impress very strongly. We are very humble regarding our present knowledge and its inadequacy. In respect to developments for gas turbines to run at really *high* temperatures we are aware that we have a kind of wild bull by the tail and we don't know quite how to let go. The fact remains, however, that some of these alloys that we have described are being used now and are being used quite sucessfully. We certainly hope to go on to bigger and better things. It should be an interesting field for a number of years to come.

Time has expired and that is all that we have time for this evening. Thank you very much.

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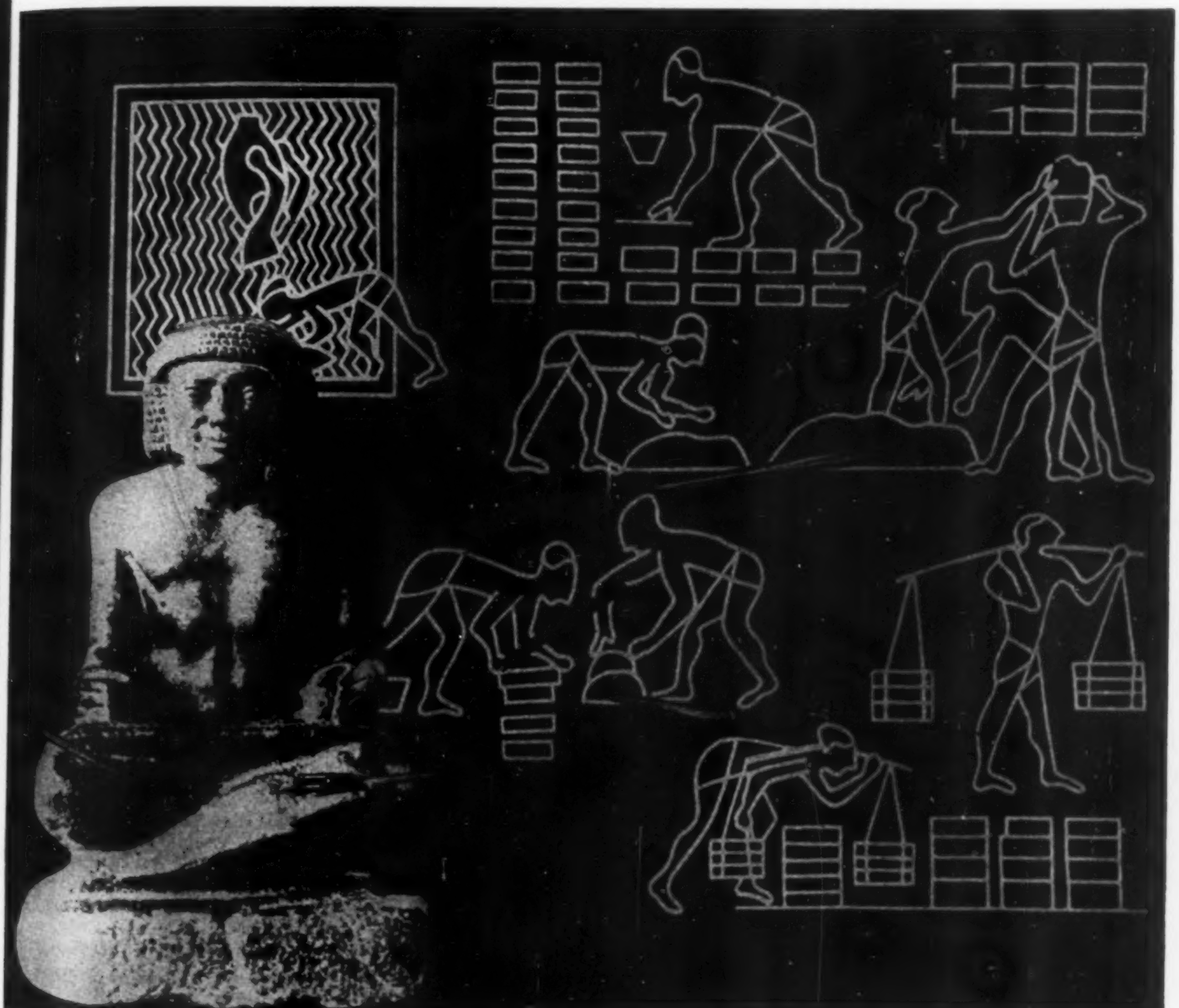

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Personal Mention

Richard J. Wooley has been promoted to district manager for United Chromium, Inc., and has just opened a new district office in Los Angeles from which he will cover the Pacific Coast states.

Robert J. Bradley has been appointed vice-president and general manager of the Bridgeport Safety Emery Wheel Co., Stratford, Conn.

H. Horrocks has resigned his position as chemist and metallurgist with American Type Founders, Elizabeth, N. J., to enter the consulting field on lead, tin, and antimony alloys.

The W. S. Rockwell Co., Fairfield, Conn., announces that Don A. Gilbert will be their representative in the Ohio district. He will have his office in Cleveland.

A. Allan Bates is resigning from the staff of Westinghouse Electric Corp., where he has been manager of the chemical and metallurgical department, to become vice-president of the Portland Cement Association in charge of research and development. His headquarters will be in Chicago.

R. M. Garrison, recently released by the Navy, has joined the Gardner-Denver Co. as tool engineer at the main plant in Quincy, Ill.

Charles S. Haughey, formerly metallurgical engineer at the Dodge Chicago Plant, Chrysler Corp., is now assistant metallurgist, Surface Combustion Corp., Toledo, Ohio, in the research and development department.

A recent Carnegie Institute of Technology graduate, Ralph A. Happe, has secured a position with the American Brass Co., Waterbury, Conn., in the research department.

Hadley F. Freeman has accepted the position of director of research for the Edwin L. Wiegand Co., Pittsburgh.

Donald Wood announces that he has formed the Hill Cross Co. in Brooklyn, N. Y. His company will specialize in electroplating with precious metals, but will also offer a service in reclaiming precious metals. Mr. Wood was formerly research engineer with National Silver Co.

Clyde R. St. John, formerly with the Aluminum Co. of America, has joined the Permanente Metals Corp., Trentwood Works, Spokane, Wash., as metallurgical engineer.

W. V. Hewitt has accepted the position of metallurgist at Walkers Ltd., Maryborough, Queensland, Australia.

Jacques J. Schrinner, formerly metallurgist in the materials laboratory of Wright Aeronautical Corp., is now metallurgist in the works laboratory of the General Electric Co., Erie, Pa.

H. E. North, Jr., has organized his own company, Burner Devices, for the manufacture of oil burners and accessories for household heating and cooking. He was previously supervisor of the materials laboratory at Douglas Aircraft.


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Personals

After leaving the Naval Research Laboratory, RALPH L. FOX ⊕ is now assistant metallurgist in the metals division of Armour Research Foundation, Chicago, Ill.

Vanadium-Alloys Steel Co., Latrobe, Pa., announces the appointment of JAMES A. CLARK ⊕ to its operations staff. He has been a captain in the U. S. Army for the past four years, serving in the Watervliet and Watertown Arsenals as assistant production superintendent and production metallurgist, respectively.

GEORGE PEARLMAN ⊕ and LLOYD KRAMER ⊕ have joined the staff of the Biad Powder Metallurgy Co., Pittsburgh. Pearlman is production manager, and Kramer metallurgist.

Pan-American Engineering Corp., Newark, N. J., has announced the appointment of HENRY E. MOORE ⊕ as a division manager. Mr. Moore was previously associated with the Remington Rand Propeller Division.

Announcement has been made of the appointment of JOHN ALICO ⊕ as director of research and development at the National Magnesium Corp. in New York City. He will have charge of an expansion program in applying magnesium to commercial uses.

J. D. HANAWALT ⊕ has been named manager of the newly organized magnesium division of the Dow Chemical Co. He was formerly director of metallurgical research.

The appointment of M. G. SEDAM ⊕ as vice-president in charge of research and production has been announced by Alloy Rods Co. of York, Pa.

JOHN CHIPMAN ⊕, professor of process metallurgy since 1937, has been appointed head of the department of metallurgy, Massachusetts Institute of Technology, Cambridge.

E. W. SCHOEN ⊕ has been appointed metallurgical engineer of Bellevue Industrial Furnace Co., Detroit.

JAY THOMAS FORD ⊕, formerly with the A.C. Spark Plug Division of General Motors Corp., is now chief chemist of Gerity-Michigan Die Casting Co., Detroit, in the Adrian Division.

Personals

Alfred H. Geisler has joined the staff of the General Electric Co. research laboratory in Schenectady, N. Y. He was previously associated with the research laboratory of the Aluminum Co. of America at New Kensington, Pa.

Announcement has been made of the appointment of C. Stewart Parsons as chief of the Bureau of Mines, Ottawa, Canada. Mr. Parsons has been chief of the metallic minerals division of the bureau since 1936.

Kellex Corp. announces the appointment of Carl E. Swartz as division engineer in charge of materials research. He will be at the research unit of the Johns Hopkins University Applied Physics Laboratory in Silver Spring, Md. Dr. Swartz was formerly chief metallurgist of Cleveland Graphite Bronze Co.

Clayton O. Dohrenwend has been appointed research consultant and senior scientist of the newly organized engineering mechanics section of the Midwest Research Institute, Kansas City, Mo. Dr. Dohrenwend was formerly chairman of the mechanics departments at the Illinois Institute of Technology and the Armour Research Foundation.

Wilbur R. Varney has recently joined the staff of Quaker Chemical Products Corp., Conshohocken, Pa., where he will act as liaison engineer between Quaker field engineers, laboratory and customers.

Arthur D. Schwope, formerly a metallurgist with the Wright Aeronautical Corp., has joined the staff of Battelle Memorial Institute, Columbus, Ohio, where he will be engaged in research on the engineering properties of materials.

B. R. Queneau, after five years with the U. S. Navy at the proving ground at Dahlgren, Va., has rejoined Carnegie-Illinois Steel Corp. in Chicago where he will be chief development metallurgist.

After being released from his connection with the Manhattan District Project, W. A. Sherrer has joined Reaction Motors, Inc., Pompton Plains, N. J., as research engineer.

Cast Steel Quality*

MECHANICAL PROPERTY TESTS were made on test bars from 48 heats with 0.15 to 0.31% carbon and 0.55 to 1.20% manganese in the as-cast, annealed, and normalized and tempered conditions. The manufacturing data, microstructure and macrostructure were examined also in an attempt to determine the factors having the most pronounced influence on the quality of cast steel.

The nature and distribution of the inclusions, grain size and method of manufacture could not be definitely correlated with the mechanical properties. However, the specimens with randomly distributed inclusions had a definite superiority over the specimens with grain boundary inclusions in respect to elongation, reduction of area, and Izod impact strength. Likewise, there was an indication that the steels with the largest aluminum additions in the final deoxidation — and therefore the finest McQuaid-Ehn grain size — had the highest impact values in the annealed and in the normalized and tempered conditions. Casting temperatures under controlled conditions may have a slight effect on the mechanical properties, but in the present work their influence was so weak that it was hardly noticeable.

The microstructures did not differ appreciably and gave no indication of the mechanical properties to be expected. There were quite distinctive differences in the macrostructure, which varied from a featureless structure to a fine and a coarse columnar structure. However, the macrostructure apparently had little if any effect on the mechanical properties.

Unsoundness, as indicated by blowholes or porosity, had a pronounced effect, particularly on the reduction of area and elongation. Its influence on these values was stronger than on the tensile strength and Izod impact strength. The effect of unsoundness on the tensile properties depended largely on the actual location of the defect in the test piece; test pieces that were blown only in the head gave quite satisfactory results. *(To page 132)*

*Abstracted from "The Influence of Melting Conditions on the Physical Properties of Steel Castings", by H. T. Protheroe. Iron and Steel Institute Advance Copy, Aug. 1944, 23 p.

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*Manufactured under Driver-Harris Patent No. 2,230,310

Cast Steel Quality

(From page 130)

In all conditions, the tensile strength increased gradually with increasing carbon content. It was impossible to determine any effect of the nickel, chromium or manganese content. Since the tensile strength variations could be attributed to variations in composition, tensile strength was not suitable as an indication of the quality of the steel. The Izod impact strength, reduction of area and elongation were better criteria but the latter two were more sensitive to the presence of unsoundness. On the assumption that the Izod value was inversely proportional to the tensile strength, the expected Izod could be calculated for each steel. The comparison of this value with the actual Izod was taken as a measure of the quality of the steel. It was apparent that the factor influencing the as-cast quality persisted after heat treatment.

The most potent factor affecting the quality was found to be the combined phosphorus and sulphur. All steels with a total sulphur plus phosphorus over 0.09% were inferior whether sound or unsound. Steels with lower sulphur plus phosphorus that were inferior invariably showed signs of unsoundness.

Metal Stampings

IN THE DESIGNING of mass production items, stampings should always be considered, and whenever practical, early consultation with stamping engineers is desirable. Designers should reconsider the design from its functional requirements rather than merely duplicate the previous product. Forward-looking stamping engineers no longer think in terms of a simple stamping but instead in terms of assemblies and subassemblies of stampings or of combined stampings with machined forgings or castings. Operations such as assembly, brazing, welding, finishing, painting, plating and even porcelain enameling will be offered by job stampers along with press work. New and better methods of inspection have been installed by stamping concerns, including magnaflux and X-ray equipment. Tremendous strides have been made in deep drawing *(Cont. on page 134)*

Metal Stampings*

(From p. 132) without intermediate annealing, in coining and close tolerance techniques and in fabricating methods such as gas and electric welding and in silver and copper brazing. Formed steel sheet assemblies are being designed with dimensional tolerances and rigidity as good as can be obtained with any other fabrication method.

Part of the unprecedented advance in aluminum stampings may be attributed to the adoption of new alloys and part to advances in manufacturing technique. In many cases, the close tolerances and short radii make the stampings interchangeable and more than satisfactory substitutes for hand and hammer work and for machined aluminum forgings. Forming of magnesium sheet on presses, however, is still in its infancy. It is not suitable for cold drawing but can be easily formed and drawn if the dies are heated to about 600° F. Successful forming and drawing of magnesium sheet presents many interesting possibilities.

Porcelain enamel may be used on steel stampings not only to provide beauty of appearance but also heat and corrosion resistance. Improved enameling steels have been announced, and a one-coat dark color is *(Continued on p. 136)*

*Abstracted from the following:

"Flexible Tools for Stamping Light Metals". *Modern Metals*, Aug. 1945.

"Stampers to Make End-Products and Subassemblies". *Steel Processing*, Oct. 1944.

"Stamping Light Metals". *Modern Metals*, April 1944.

"Deep Drawing of Windshields for Heavy Caliber Shells". *Steel Processing*, Jan. 1945.

"Mass Production of Aircraft Expanded Through Increased Use of Stampings". *Steel Processing*, May 1945.

"Porcelain Enamel on Steel Components in Postwar Era", by G. H. McIntyre. *Steel Processing*, Feb. 1945.

"Precision Mindedness in Press Operations", by R. W. Glasner. *Modern Industrial Press*, Feb. 1945, p. 22, 24.

"Greater Output Through Application of Modern Press Design", by R. W. Glasner. *Steel Processing*, March 1945.

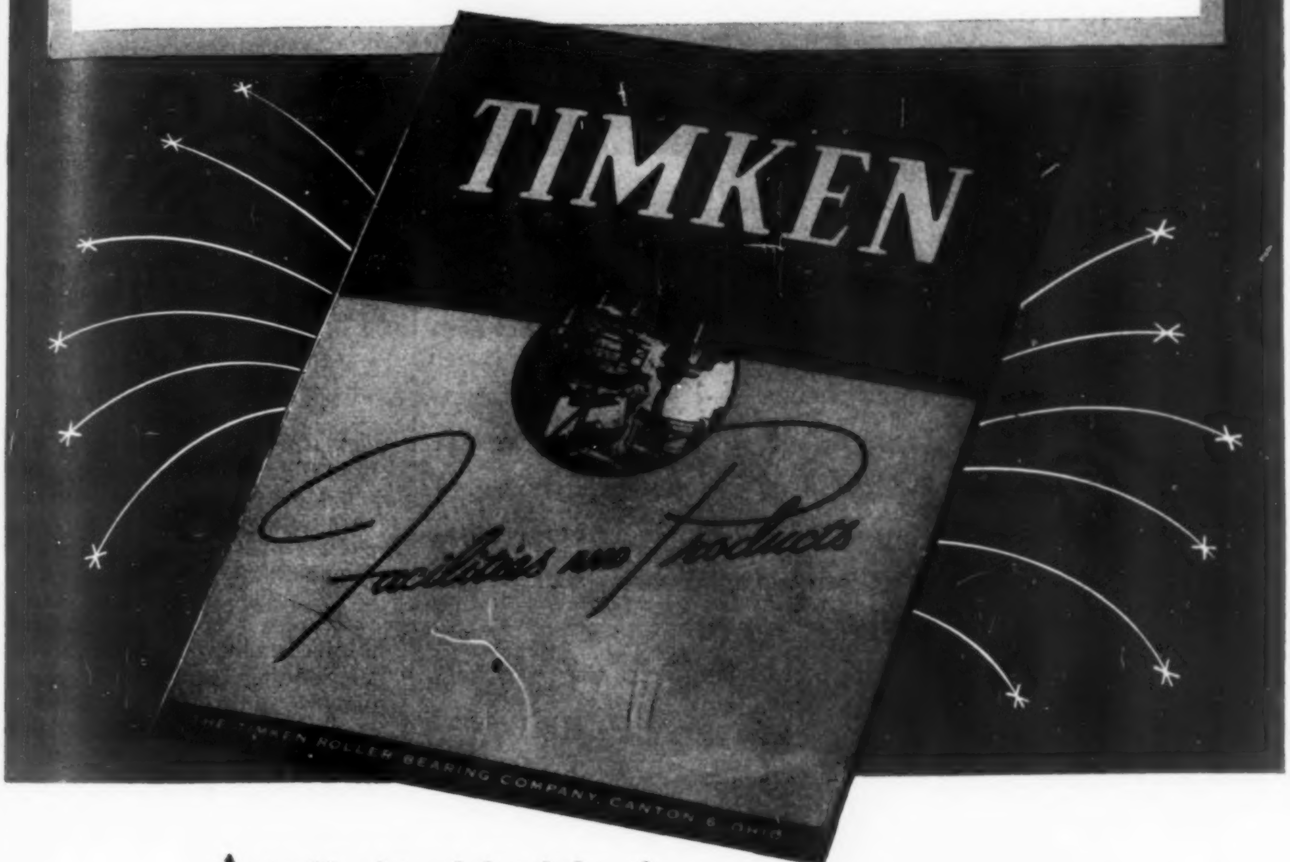
"The Effect of War Production on Metal Stamping Technique", by Howard Wolf. *Finish*, May 1945.

"Complete Assembly of 57-Mm. Gun Carriages by Pressed Metal Producer". *Steel Processing*, Dec. 1944.

"Welding and Brazing of Stamped Parts". *Western Machinery and Steel World*, June 1945.

"Press Forming Possibilities of Heavy Sheet and Plate". *Product Engineering*, Feb. 1945, p. 125 to 129.

A New Guide for Alloy Steel Buyers is Just Off the Press!



A graphic pictured description of facilities available to you in the world's largest alloy steel specialty mill producing Bars and Seamless Tubes.

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★ YEARS AHEAD — THROUGH EXPERIENCE AND RESEARCH

SPECIALISTS in hot rolled and cold finished Alloy Steel Bars for forging and machining including Stainless, Graphitic and Tool Steel analyses. Also Alloy Steel Seamless Tubes for mechanical and high temperature applications.

Metal Stampings

(From p. 134) already a practical possibility with a semi-matte or glossy finish. The enameling industry is at last approaching the possibility of a one-coat white application on steel without a ground coat. Cover coat white enamels of high opacity, better acid resistance and improved workability are also available. All enamelers should be familiar with the various types of welded joints which can be enameled successfully. It should be determined if copper brazed joints can be satisfactorily enameled.

The possible applications of new production techniques used in the manufacture of the deep drawn steel shell cases and the windshields for armor-piercing steels are interesting. Experience gained during the war in the production of parts stamped, formed or drawn cold from heavy plate up to ¾ in. thick has indicated many other suitable applications. Advances have also been made in the manufacture of large and heavier hot pressings. Low carbon steel is preferred. Cold rolled steel has the best finish but this has little value if intermediate anneals are required. High strength steels need generous bending radii. Stainless steels are expensive but have excellent drawing properties. Aluminum and brass are used for heavy work, but copper and magnesium are seldom used. Blanking operations on heavy material are limited by the size of the available press. Forming operations are limited largely by the allowable radii. In piercing holes the diameter should not be less than the stock thickness. Rectangular draws are more difficult and more limited by press capacity than round draws. The deepest draws require hydraulic presses.

The pressed steel industry has realized that it would be possible to expand greatly the market for stampings if an inexpensive method for the production of short run dies and tools could be devised. The aircraft industry has made marked progress in this direction with the use of zinc alloys, plastics, rubber and plywood. Kirksite, a zinc alloy containing aluminum and magnesium, has been frequently used for tools for blanking, forming and deep drawing aluminum. Plastics are not a cure-all for emergency tooling but have made it possible to solve many difficult problems. One type combining *(Cont. on p. 138)*

Metal Stampings

***(From p. 136)* ceramics and thermoplastic material is used for profile duplicating blocks, stretch press form blocks and stretch dies. The other is a cast phenolic with high compressive strength. These tools and dies should be very useful not only for trial runs before permanent tooling is installed but also for runs where only a relatively few pieces are required.**

New presses have many advantages over older models. Presses have steadily increased in size and capacity, and many specific improvements have been made. The development of hydraulic presses has been rapid. More accurate controls and faster speeds are noteworthy. Stamping plants should take advantage of the improvements in modern presses. The press manufacturers can provide much help to the stamping producer who is buying a new press. Even if the best press for the job is expensive, the increased cost per stamping is negligible. Only the most efficient kind of press will be good enough for the exacting demands of precision stampings at low cost.

Barium Metal*

DESPITE THE plentiful distribution of barium minerals, a cheap means of preparing barium metal is not yet known. This is because of its great chemical activity and difficulty of isolation. The Guntz process involves the making of barium by the reduction of barium oxide with either silicon or aluminum. The reduced barium is removed by heating the residue under a vacuum so the barium is distilled off and condensed in a cool part of the apparatus. The relation of the reducing agent to the oxide in the reaction mixture is important. Guntz suggested the use of three parts of barium oxide to two of aluminum. It is believed that the orthosilicate is formed when silicon is employed as the reducing agent, while the monoaluminate is produced in the aluminum reduction.

The diffusion of the barium oxide toward the reducing agent controls the speed of the operation.

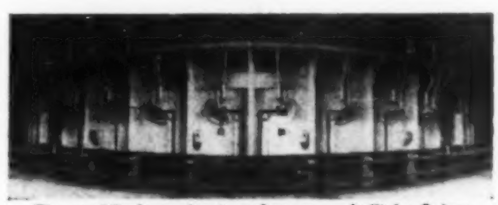
(Continued on page 140)

*Abstracted from "Processes for Making Barium and Its Alloys", by W. J. Kroll. Bureau of Mines Information Circular, I.C. 7327, Aug. 1945.

ENGINEERED HEAT

for production Quality

Salem Engineering Company designs and builds industrial furnaces and heating equipment for production of ferrous and non-ferrous metals . . . for metal fabricating . . . for forging and foundry operations. Where new and revolutionary ideas necessitate ingenious use of heat, Salem engineers survey the problem and "come up" with not only the heating solution, but in many cases, the means of material handling. In short . . . Salem tailors its equipment to a streamlined flow of production.



The world's largest rotary furnace . . . built by Salem

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Barium Metal

(Continued from page 138)

Additions of materials such as calcium fluoride which act as mineralizers may also have an influence on the rate of diffusion. It is felt that the reduction of barium goes by way of the silicide or aluminide, although this is not yet certain for the reduction of dolomite with aluminum or silicon.

Barium alloys can be made readily either by the direct reduction of the oxide with silicon or aluminum; by the reduction of the chloride with calcium, of the fluoride with aluminum, or of the chloride-oxide mixtures with magnesium; or by the sodium reduction of the chloride in the presence of heavy or light metals. All the methods using metal solvents for the barium have the disadvantage that low grade alloys have to be submitted to the dissociation procedure at fairly high temperatures in a good vacuum. The alloys always pick up some oxide which stays behind in the barium metal. Fusion electrolysis with heavy metal cathodes, in which the heavy metal may be introduced also as a salt or taken from a subsidiary soluble anode, has been frequently used for making lower grade alloys. The well-known Frary metal with about 2% barium, some calcium and the remainder lead was made this way.

Light metal barium alloys may sometime find practical application, but present methods of production prohibit their use as a getter metal because of the presence of small amounts of chlorine which cannot be removed by the vacuum treatment, or because they are stable in a vacuum. Alloys of barium and mercury may be made by aqueous electrolysis but the mercury cannot be removed completely from these alloys. Multiple equilibrium reactions may take place between alkali, alkaline earth metal chlorides, and any metal of these groups alone or in the presence of or in solution in light or heavy metals; this method generally yields alloys which otherwise would be difficult to prepare.

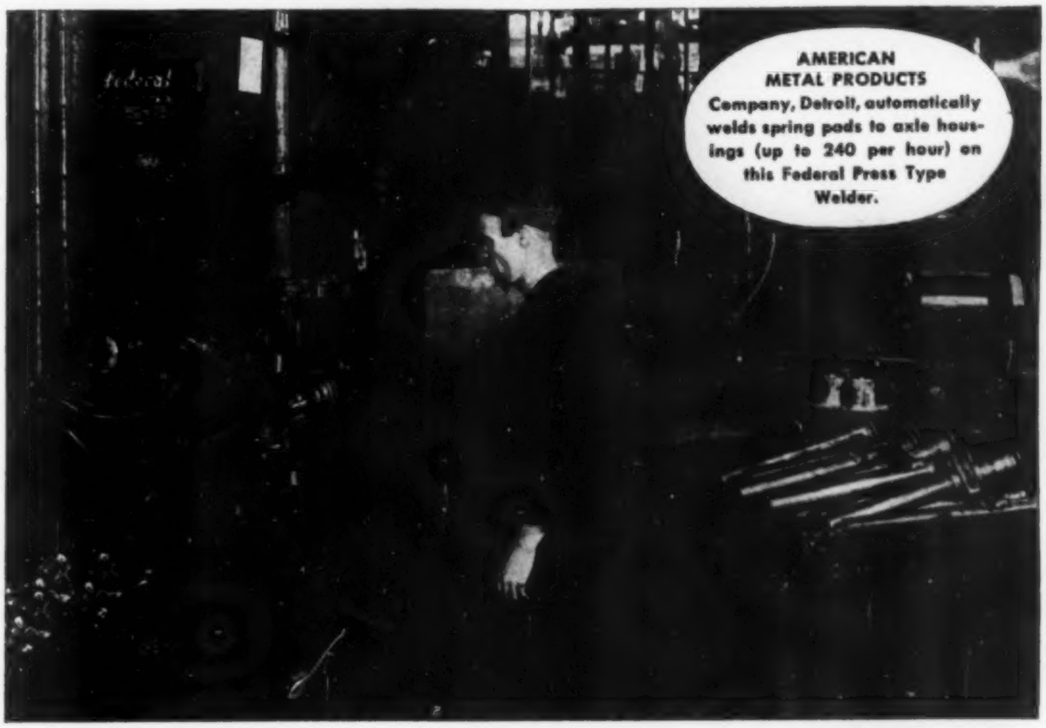
Two apparatuses for making barium by the Guntz process are described in detail. One utilizes high frequency heating with downward condensation while the other involves external heating and upward condensation. The best results are obtained at 2100° F., but in the second apparatus where external heat is applied through a refractory tube *(Cont. on page 142)*

Auto Industry Has Many Examples of "Necessities Production" Sped by Federal RESISTANCE WELDERS


ACCESSORIES


RADIO PARTS


PRODUCTION SHORT CUTS



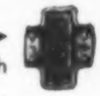
AMERICAN METAL PRODUCTS Company, Detroit, automatically welds spring pads to axle housings (up to 240 per hour) on this Federal Press Type Welder.


APPLIANCES


UTENSILS

PROJECTION WELDED — Thousands of variations of the typical items above are produced at low cost on Federal Welders described in Bulletin 4520.

For instance, you can take a heavy-gauge steel tube like this,→ which is a rear axle housing component, and a heavy gauge stamping like this, → which is a spring pad; insert them in a Federal PA-4 Press Type Welder with simple dies (shown above) and they come out as though one piece of metal . . . but stronger. Fifteen seconds total time. That's four pieces a minute.



Note the three nubs projecting inwardly on each side of the saddle portion of the stamping. At these points of contact between stamping and tube, welds initiate. Under heat and pressure the parts are forged together in these areas, the junctures becoming stronger than surrounding parent metal.

To the vast saving of time, against previous joining methods, add time savings on final assemblies and great economy in material resulting from this design. (Heavy castings were used where lighter but tougher stampings now do the job). There you find the reasons why industries noted for making the most of needed goods at the lowest cost are largest users of Federal Resistance Welders.

This is typical of hundreds of Federal welded jobs produced by the American Metal Products Company of Detroit, makers of quality parts for many industries. It is typical too, of thousands of other production-speeding, cost cutting methods possible with Federal Resistance Welders.

Every delay of full-scale production for the dammed-up needs of world markets through shortages of material or of work makes the need for eventual production speed more important . . . lowering of unit costs more urgent. When you find out (through the Federal Engineering Service nearest you) how you can cut cost and time in YOUR production with automatic welding, be sure that you get Resistance Welders by . . . Federal

BULLETIN SP 346 Describing Federal Spot, Flash, Projection, Seam and "Gun" Welders is yours for the asking.

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The Warren City Mfg. Co., Warren—WARCO PRESSES and PRESS BRAKES

Barium Metal

(Starts on p. 138) the temperature measured between the tube and the reaction crucible was 2190° F. The barium oxide must be freshly prepared. Under optimum conditions 2.2 parts of barium oxide and 0.21 part of aluminum were consumed to produce one part of barium.

Based upon the experience of the silicothermic distillation plants producing magnesium, barium probably could be made on a large scale at a cost of less than 45¢ per lb. as compared with the present price in small lots of $15 per lb. The chemical methods of making alloys would compete on this cost basis.

Endurance of Fillet Welds*

FATIGUE TESTS under axial loading were made on A.S.T.M. A7 steel specimens so designed that the loads would be transmitted through shearing of the fillet, plug or slot welds. Joints of these types might be used for connecting one end of a flat plate of a channel tension member in a bridge or building to a gusset plate or chord member. If cycles of widely variable stress will be frequently repeated, the base material is almost always the critical element and will probably fail at an uneconomically low maximum stress. Under these conditions, fillet, plug or slot welds are much inferior to butts.

For a welded connection in shear across a faying surface, no arrangement is much more efficient than a fillet across the free end continued into a fillet along each side of the narrower connected part. With such welds, dependable values of fatigue strength of fillet welds in shear on the throat are given in the table as Series 1. Fatigue strength of fillet welds in tee joints with the stem material subject to tension perpendicular to the flange will depend on the size of the fillet. Values of the shear on the throat for $\frac{5}{16}$-in. fillets are given in Series 2. Dependable values of fatigue strength of the main material under *(Cont. on p. 144)*

*Abstracted from "Fatigue Strength of Fillet, Plug and Slot Welds in Ordinary Bridge Steel". Report No. 4 of the Committee on Fatigue Testing (Structural) of the Welding Research Council of the Engineering Foundation.

Fillet Welds

(From p. 142) tensile stress when connected by fillet welds not concentric with the part (a single lap splice) are given in Series 3.

Plug welds have a dependable strength in shear for 100,000 cycles corresponding to Series 1, but this should be reduced to three-quarters the value given for 2,000,000 cycles. Main material connected by plug welds has the dependable values in shear as given in Series 3. Slot welds, longitudinal or transverse, have endurance strengths too far below the values given to be practical for parts subject to cyclical stress.

Fillet welds in holes have dependable fatigue strength in shear equal to Series 1. Continuous plates under tension lose comparatively little fatigue strength through the welding of an attachment to one side only by transverse fillet welds but lose possibly one-third of their fatigue strength through the welding or riveting of such attachments to both sides at a common section.

One set of specimens was helped by peening while another was greatly harmed. Therefore, peening should not be used for bridges until more information on this practice is available.

Fillet welds subjected to a combination of shear and bending (as in beam web connections) show an extreme fiber shearing stress as high as in fillet welded connections in pure shear, but fillet welds simulating top and bottom flange connections show very little fatigue strength and should not be used for cyclical loads. Fillet welds between webs and flanges in flexural members are being studied.

Fatigue Strength of Fillet Welds

	Series 1		Series 2		Series 3	
Stress Cycles (N)	100,000	2,000,000	100,000	2,000,000	100,000	2,000,000
Material in tension						
Full reversal	11,000	8,250	12,000	6,000	9,600	5,400
Zero to max.	22,000	16,500	16,000	8,000	16,000	9,000
Max. to ½ max.	44,000	33,000	32,000	16,000	24,000	13,500
Material in compression						
Zero to max.	28,000	21,000				

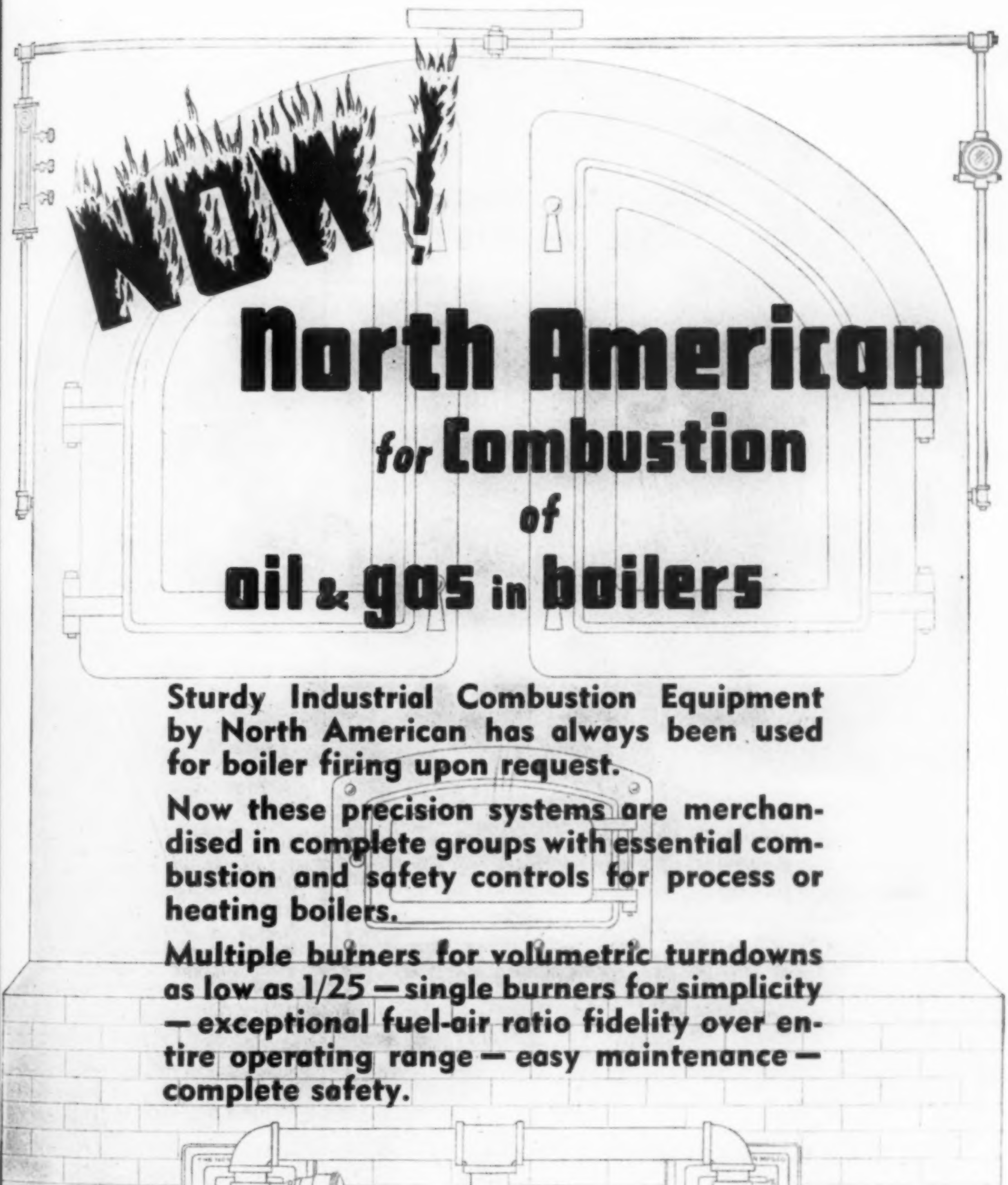
Electric Furnace Linings★

THE SEVERE SERVICE to which refractory linings are subjected in the basic electric furnace is indicated by a life only a third to a fourth that obtained in comparable positions in the openhearth. This difference is due particularly to the intense nature of the source of heat, its relative proximity to the sidewalls and roof, the intermittent heating, the frequent cooling, the alternations between oxidizing and reducing conditions, the large proportion of fluorspar in the slag, volatilization of the fluxes, and the high percentage of alloy steels made.

Semi-stable dolomite (S.S.D.) bricks have been widely adopted in England for basic electric sidewalls, arches, jambs and bottoms and have been found superior to the basic refractories previously used. S.S.D. performs very creditably in sidewalls; one user has reported an increase of 50% in the average wall life over magnesite and chrome magnesite. Chrome magnesite, magnesite, S.S.D. and stable dolomite are all used under the hearth. Rammed dolomite is used exclusively for the actual hearth. S.S.D. compares favorably with silica and chrome magnesite in door arches and jambs and is decidedly better than magnesite and firebrick. The highest taphole life was quoted for S.S.D. Sidewalls of the Greaves Etchells conducting-hearth furnace are also being made successfully of S.S.D. A trial under severe conditions of S.S.D. for the roof of a four-ton furnace was promising. Such a roof makes possible a higher furnace temperature and materially increased sidewall life. Cutting and mechanical abuse during installation should be avoided and dry jointing material should be used to avoid hydration.

Dolomite bricks stabilized against hydration are made in England by the addition of finely ground serpentine to the dolomite before firing. Boric oxide is added, apparently for stabilization against dicalcium silicate dusting. S.S.D. brick is made from an unstabilized dolomite clinker. The unstabilized brick represents the maximum slag resistance attainable *(To p. 148)*

★Abstracted from "Dolomite Linings for Basic Electric Arc Furnaces", by E. C. Brampton, H. Parnham and J. White. British Iron and Steel Institute Advance Copy, Oct. 1945, 32 p.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BRANCH OFFICES IN PRINCIPAL CITIES

Furnace Linings

(Cont. from page 146) with dolomite, short of removing the lime or adding large amounts of magnesite. S.S.D. is impregnated with tar to hinder hydration.

S.S.D. bricks fail in service mainly by fluxing at the working face and splitting off behind the working face. The former is continuous and is a more or less intrinsic property of a given refractory in a given environment. The latter is common to all basic refractories and is intermittent and recurrent; it appears to vary considerably with different practices and different positions in the furnace.

The principal materials picked up in the furnace are iron oxides, SiO_2, Cr_2O_3, MnO, sulphur, and perhaps Al_2O_3. A considerable proportion of the SiO_2 apparently comes originally from the silica roof. The different materials picked up show different powers of penetration. The working face of the brick tends to acquire increased resistance to fluxing while in service as a result of drainage and of migration of the lime (in the form of fusible compounds) away from the hot face. The zone in the immediate vicinity of the working face of used bricks consists mainly of the highly refractory combination of spinel and periclase with other divalent oxides in solid solution.

Flaking or splitting off of the brick 1 to 2 in. behind the hot face is believed associated with the loss of hot strength consequent on the penetration of fluxes and liquid formation. Stress is laid on the importance of maintaining adequate support at the hot face and of avoiding excessive undercutting. A few samples show a tendency toward spalling farther back from the hot face, due presumably to stresses and the relative weakness of this zone. The phases identified in the various zones are consistent with the known equilibrium phase data for the system CaO-MgO-Fe_2O_3 (FeO)-Al_2O_3-SiO_2.

Sulphur printing on bromide paper has been used to identify the presence of sulphide in used bricks. The concentration of the sulphide is low near the hot face and reaches a maximum some distance into the brick. This is probably responsible for a certain softening observed in a zone immediately beyond the limits of flux penetration.

The iron oxides in the brick undergo alternating oxidation and reduction; *(Cont. on page 150)*

Furnace Linings

(Starts on page 146)

this is not confined simply to the hot face. Analyses of the gas samples drawn from furnaces during the refining period indicate that very highly reducing atmospheres may arise at certain stages and that reduction of iron oxide at 2910° F. to a stage intermediate between FeO and Fe_3O_4 should be expected.

Samples of refining period fumes show that the "fixed constituents" are mainly MgO, CaO, iron oxide and silica, with appreciable amounts of apparently combined carbon and sulphur. These fumes are an important source of flux deposition on the refractories. Their compositions are such that basic refractories will be much less affected by fumes than acid.

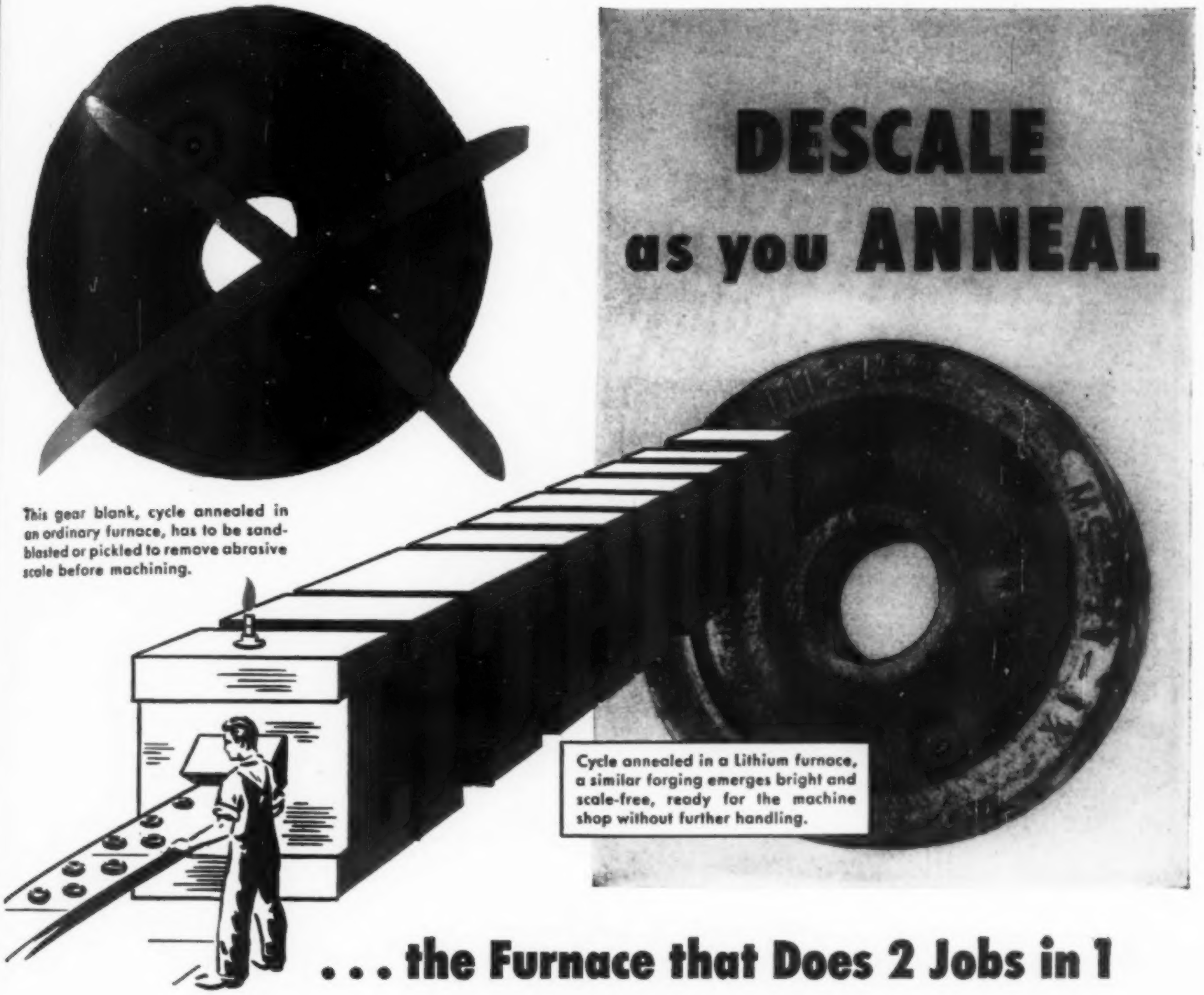
Quality Control*

RESPONSIBILITY for statistical quality control is centered in a unit of the inspection office. It services the major portion of Lockheed operations.

In the receiving inspection section, advantages have been obtained by replacing previous methods of sampling by more rational ones on a statistical basis and by substituting sampling inspection in some cases for detailing. The greatest advantages, however, have come from the use of inspection data to evaluate vendors and to stimulate and assist them to improve the quality of their products. This program is in full swing on instruments and other government-furnished equipment. Vendor evaluation for vendors producing Lockheed parts is being slowly expanded. The statistical reports enable the field service representatives to single out trouble spots at the vendors and to obtain corrective action at the point of manufacture.

Effective quality control requires location of the cause of the unsatisfactory product and correction at the source. This process has been facilitated by a simple system of record keeping involving the use of a set of rubber "quality stamps" for identifica- *(Cont. on p. 152)*

*Abstracted from "Statistical Quality Control at Lockheed", by James R. Crawford and Preston C. Hammer. Quality Control Reports, No. 9, Sept. 1945, 17 p.



This gear blank, cycle annealed in an ordinary furnace, has to be sandblasted or pickled to remove abrasive scale before machining.

Cycle annealed in a Lithium furnace, a similar forging emerges bright and scale-free, ready for the machine shop without further handling.

. . . the Furnace that Does 2 Jobs in 1

Typical of the faster, more economical production possible with Lithium equipment is the current experience of a leading midwest automotive parts manufacturer. One Lithium furnace in his plant can cycle anneal and simultaneously descale 50 tons of forgings every day at a cost of less than 50 cents a ton for the descaling atmosphere . . . a fraction of the expense of the old-fashioned cleaning methods which Lithium makes obsolete!

Lithium-treated steel forgings emerge from this furnace free of scale, with the desired metallurgical structure and hardness and ready for machining. Thousands of these gears have been put through the machine line in this plant after Lithium descaling without further handling.

Streamlining like this means more profitable operation. Let a Lithium representative show you how your production schedule can be speeded up and your operating costs substantially reduced by installation of this revolutionary equipment.

SEE WHAT YOU SAVE!

- No sandblasting necessary . . . lengthens tool life.
- No acid pickling tanks needed . . . no more sewage disposal problems.
- Floor space used for cleaning operations can be turned to productive work.
- Labor and handling costs for cleaning entirely eliminated.
- Above all, TIME! Lithium does away with one complete operation, eliminates detours between furnace and machine shop!

LITHIUM

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Quality Control

(From p. 150) tion purposes. The quality stamp procedure by which trouble areas in production and tooling may be found at the lowest level of supervision is proceeding smoothly. The effect of this method of obtaining better workmanship has been most gratifying. It has functioned especially well in subassembly and assembly departments but has encountered difficulty in fabrication departments caused by the existence of two shifts and the impracticability of getting a separation of the parts made under each supervisor. Here the percentage of rejections is kept by sections. Whenever a point goes out of control, it is usually easy to find and eliminate the contributing factors.

Statistical control of the spot welding process affords an example of such methods at their best. As the results of charts based on sample coupon tests, remarkable improvement in weld uniformity has been obtained. In the machine shops and fabrication areas, however, the great variety of parts makes it impossible to keep charts on any appreciable fraction except in cases where certain parts are being rejected too frequently. In a landing gear trunnion, for instance, difficulties with tolerances on the inner diameter were found to come from the use of a boring machine on heat treated material. The solution was the use of a honing machine to finish the operation.

Measurements of the output of inspections have been very valuable. One of the big obstacles to the successful use of control charts arose from the failure of the customary p-chart limits. This was overcome by a "moving range technique" which treats each weekly value as a measure of the quality regardless of the number of contributing parts. Rejections in the pre-flight shakedown and in flights are systematically compiled on the basis of the part of the plane causing trouble. These data are sent back to the sources of trouble.

A new "executive's quality audit" summarizes the defectiveness by departments. A weighted average is also given for the quality level of all departments under each superintendent. Experience has shown that limits are useful even when set from only ten or twelve points. This audit gives the management a picture of the quality level of the entire production. ◉